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INTEGRATION OF BUILDING AND ENERGY TECHNOLOGY WITH ON-SITE WASTE MANAGEMENT IN THE YEAR 2000

by

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FOREWORD

The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water systems. Under a mandate of national environmental laws, the agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. The Clean Water Act, the Safe Drinking Water Act, and the Toxics Substances Control Act are three of the major congressional laws that provide the framework for restoring and maintaining the integrity of our Nation's water, for preserving and enhancing the water we drink, and for protecting the environment from toxic substances. These laws direct the EPA to perform research to define our environmental problems, measure the impacts, and search for solutions.

The Water Engineering Research Laboratory is that component of EPA's Research and Development program concerned with preventing, treating, and managing municipal and industrial wastewater discharges; establishing practices to control and remove contaminants from drinking water and to prevent its deterioration during storage and distribution; and assessing the nature and controllability of releases of toxic substances to the air, water, and land from manufacturing processes and subsequent product uses. This publication is one of the products of that research and provides a vital communication link between the researcher and the user community.

This report is a desk-top study of alternative energy use and recovery systems as related to future construction and social patterns.

Francis T. Mayo, Director
Water Engineering Research Laboratory

ABSTRACT

During this study the feasibility of integrating waste management, water supply and on-site energy generation was examined with the objective of improving the overall resource efficiency of the typical residential unit. This report can be used by members of the various research and development communities to gain understanding of other fields and is meant to foster the appreciation of the interrelationships between residential utility systems.

- Efficiency - The use of resource-efficient technologies (whether low flow shower heads or well insulated structures) is almost always the most cost-effective method to reduce consumption.
- Simplicity - The simpler the equipment, the less chance that it will break down, and the lower the costs of operation and maintenance.
- Marketability - The consumer will buy something out of the ordinary when it does the job for a much lower cost or when it does a better job. Novel utility systems must provide better service to achieve widespread market penetration. Novel systems which provide equal service while using less of a particular resource will be purchased only if that resource is costly or in short supply.

This report was submitted in fulfillment of Contract 68-03-2893 by Urban Systems Research and Engineering, Inc. and Total Environmental Action under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period October 1979 to September 1980, and work was completed as of September 1980.

CONTENTS

Forword iii
Abstract iv
List of Figures vi
List of Tables vii
Acknowledgment viii

1. Introduction 1
2. Conclusion and Recommendations 3
3. Assumptions and Technologies 15
4. Issues of Integration 35
5. Integrated Systems 44

Appendices

A. Technology Evaluation 76
B. Interview Reports 100
C. Five Anaerobic Digester Designs for the Base Case House 147

LIST OF FIGURES

Number		Page
1	Waste Disposal Options	4
2	Traditional Waste Disposal	5
3	Baseline House	33
4	Year 1980 Market House	34
5	Example Site Constraints and Options for Surmounting Them	39
6	Conceivable Integrations	45
7	Schematic - Residential Anaerobic Digester	52
8	Automatic Composter	57
9	Basin Type Solar Still	65
10	Wick Type Solar Still	66
11	Performance of Solar Stills	68
12	Schematic Diagram of Greywater Pasteurization by Solar Heat	73

LIST OF TABLES

Number		Page
1	Non-traditional Water/Wastewater Technologies	11
2	Solid Waste Technologies	13
3	Household Wastes and Example Management Alternative	17
4	Energy Systems	21
5	Resource Requirements for Baseline Year 2000 House and Year 1980 Market House	30
6	Integrations Not Studied	46
7	Integrated Utility Systems	47
8	Annual Nitrogen and Phosphorous Production	49
9	Anaerobic Digester Design	54

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Bob Siegrist of Rural Systems Engineering brought his considerable experience with individual water and wastewater systems to bear as a consultant, with gratifying results for the project.

SECTION 1

INTRODUCTION

The rising cost of fuel and recurring water shortages throughout this country have caused increasing demand for alternatives to the standard household utility system. The New England area, which has been hard hit by the rising cost of imported oil, has seen an unprecedented growth in the use of wood for space heating; the recent drought in California resulted in the development of many unique water reuse schemes. This study was commissioned by the U.S. Environmental Protection Agency to examine the potential and feasibility of integrating waste management, water supply and on-site energy generation to improve the overall resource efficiency of residential units.

The typical 1980 residential construction is inefficient both in terms of energy and water consumption. It is the conclusion of this study that more efficient use of resources to perform the same tasks is the most cost effective approach to reducing consumption. Thus, low water use fixtures, greater insulation, more efficient furnaces and similar approaches show greater promise than reuse technologies such as greywater heat recovery, greywater reuse or waste heat recapture.

While there is significant, comprehensive ongoing utilities research in each area, the purpose of this study was to provide a survey across disciplines with the particular focus on integration. The research staff for this project reflected this interdisciplinary approach and included sanitary engineers, a resource economist, a solar architect and a mechanical engineer -- all with expertise in the design of alternative residential waste management and energy systems. This report will provide members of the various research and development communities with an understanding of each other's fields sufficient to foster the appreciation of the potential total costs and benefits of various alternative technologies.

The study attempts to project viable utility systems for the typical or baseline single family residence in rural and suburban areas (beyond the projected reach of sanitary sewers) for the year 2000. A range of residential units are embraced by this scenario, including market houses, mobile homes, custom homes and small multi-unit construction.

An assessment of the 1980 state of the art provides the basis for further analysis. The findings of this task are summarized in Appendix A, Technology Assessment, and are supported by Appendix B, Interview Reports. Projections for resource availability and residential patterns were evaluated to determine the most likely setting for new residential construction in the year 2000.

Finally, integrated on-site utilities, defined as systems which utilize outputs from one on-site system as input for another, were evaluated for feasibility, with a detailed analysis performed in the most promising cases. As a feasibility study, the level of analysis has, out of necessity, been preliminary, but sufficient to achieve the goal of screening out various options.

Any attempt to predict the actual, or even relative, resource costs in the year 2000 is unrealistic. Evaluations in this report are based on the quantities of a resource (liters of water, BTU's of heat) saved rather than costs. If one assumes that resources will become scarcer over the next twenty years, it is then logical to assume that significant reductions in the amounts of resources used may have a positive impact on overall costs.

For this analysis, two major categories of integrated systems were considered: those which utilize the resource value in a waste stream, and those which utilize energy generated on-site to treat a waste stream in a novel manner. The evaluations have addressed several questions about the installation of an alternative utility system:

- What are the marginal savings in overall resource consumption?
- What are the space and/or labor requirements?
- What are the risks, either in terms of performance or safety?
- How can the risks be mitigated?
- Under what circumstances would these systems be most attractive?

Recommendations for further research have been made based on the insights gained during the study.

Section 2, Conclusions and Recommendations, identifies priorities for additional efforts to improve the resource efficiency of residential units. These recommendations are directed toward the residential water/wastewater and solid waste management systems.

Section 3, Assumptions and Technologies, presents a discussion of the utility systems examined and the assumptions used throughout the analysis. A Base Case house has been developed to be used as a benchmark for the evaluation of alterative designs.

Section 4, Technical Issues of Integration, addresses the incentives, constraints and barriers to implementation of innovative utility systems. Market penetration and compatibility with building technology are two of the issues discussed in depth.

Section 5, Integrated Systems, presents evaluations of several novel integrated systems. The process by which the most feasible systems were chosen for evaluation is reviewed.

SECTION 2

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

The opportunities for improving the overall resource efficiency of new single family homes in unsewered areas were examined, with particular emphasis on waste management systems. The following conclusions are summarized from Sections 3 and 4.

- Efficiency--The use of resource-efficient technologies (whether low flow shower heads or well insulated structures) is almost always the most cost-effective method to reduce consumption.
- Simplicity--The simpler the equipment, the less chance that it will break down, and the lower the costs of operation and maintenance.
- Marketability--The consumer will buy something out of the ordinary when it does the job for a much lower cost or when it does a better job. Novel utility systems must provide better service to achieve widespread market penetration. Novel systems which provide equal service while using less of a particular resource will be purchased only if that resource is costly or in short supply.

Figure 1 shows management options for the types of wastes generated within the home (toilet, greywater, food, paper, refuse). While there are numerous potential management schemes, the vast majority of homes currently utilize some version of the traditional system (Figure 2) where solid wastes are hauled off-site for disposal. Since food wastes may be handled as a component of either the solid waste or (via the garbage disposal) the wastewater, it is important to note which approach is being considered. A wastewater system which cannot accept food waste would be restricted in the marketplace. Because of the obvious interdependence of the water supply and wastewater management systems within an individual home, these systems are treated as a single utility.

RECOMMENDATIONS

The detailed discussion of RD&D recommendations presented in this section is organized by traditional and non-traditional technologies for both the water/wastewater and solid waste streams.

- Traditional Water/Wastewater Technologies - The first priority for improving the resource efficiency of residential water/wastewater

Figure 1

WASTE DISPOSAL OPTIONS

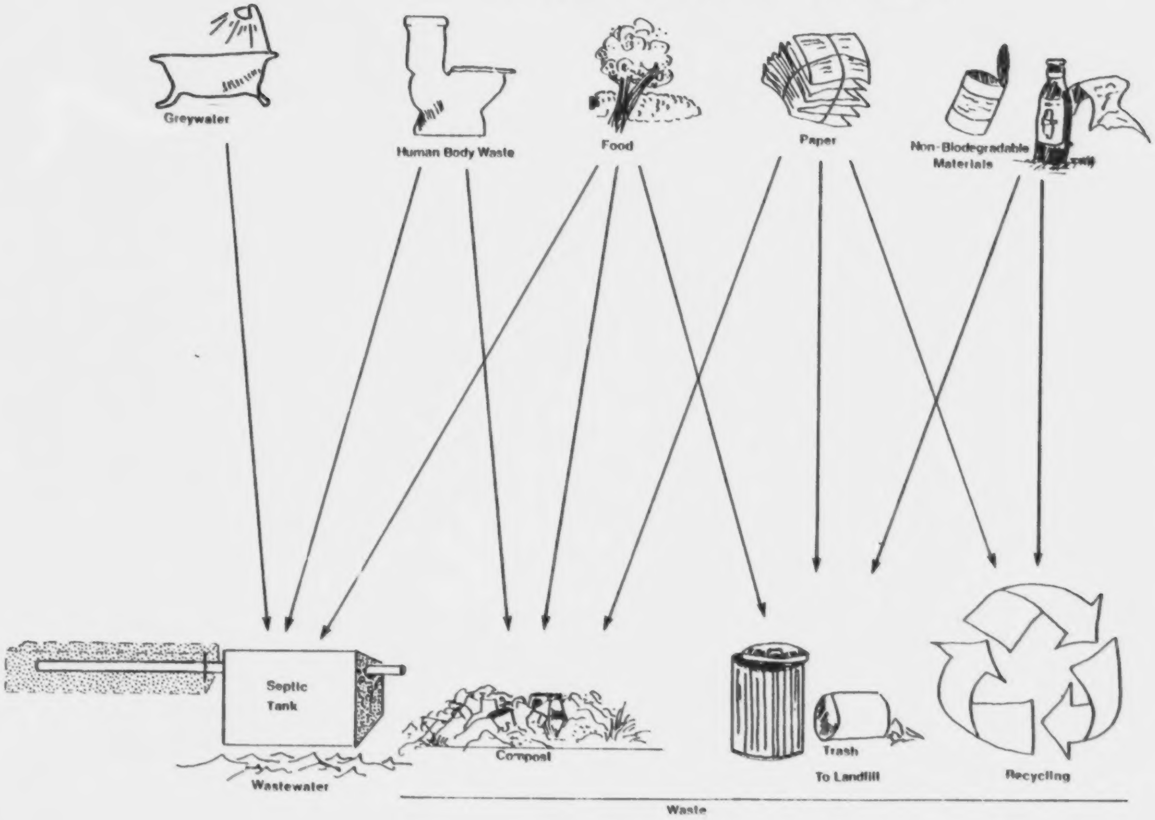
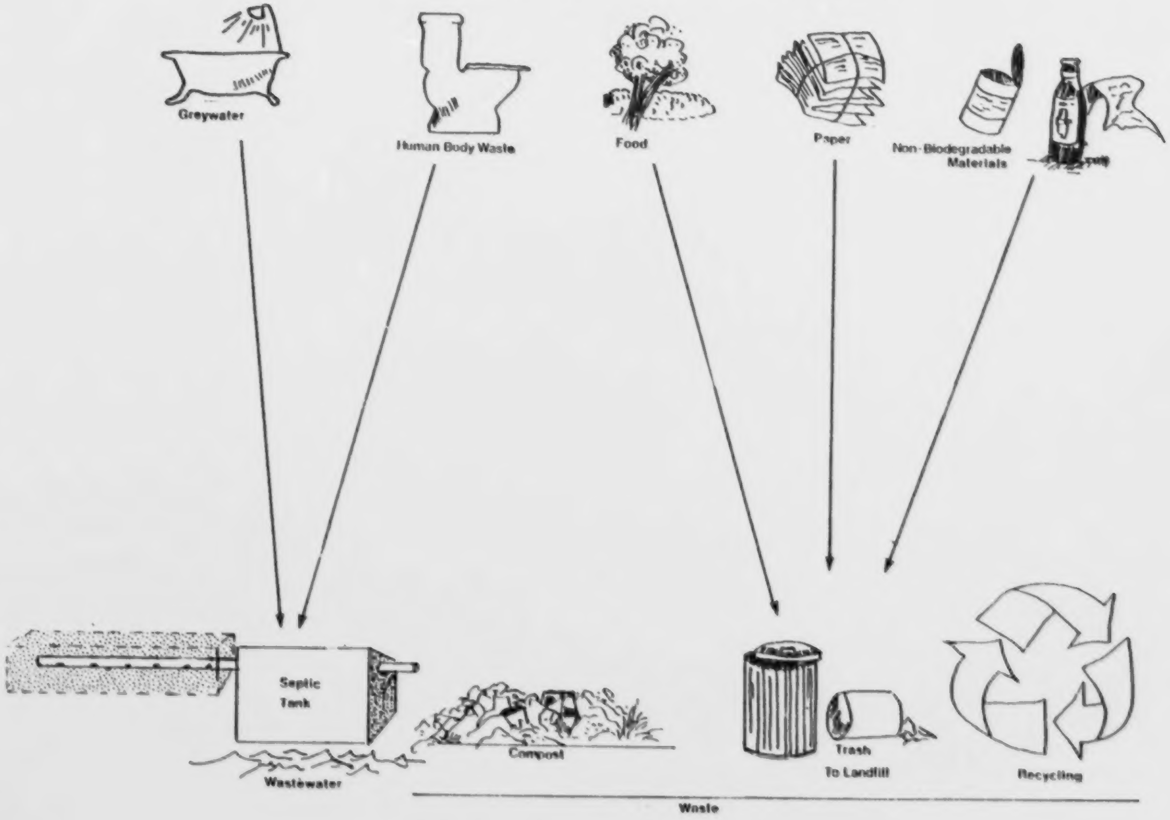

Greywater
Human Body Waste
Food
Paper
Non-Biodegradable Materials
Septic Tank
Wastewater
Compost
Trash
To Landfill
Recycling
Waste

Figure 2

TRADITIONAL WASTE DISPOSAL


Greywater
Human Body Waste
Food
Paper
Non-Biodegradable Materials
Septic Tank
Wastewater
Compost
Trash
To Landfill
Recycling
Waste

systems should be the implementation of water efficient technologies. Simultaneously, research should be directed at improving the performance of traditional on-site wastewater management technologies under the resulting low-flow conditions. Research efforts in these two areas show the most promise for widespread use in both new construction and rehabilitation and thus are the most direct path toward resource efficiency.

- Non-traditional Water/Wastewater Technologies - Most non-traditional water/wastewater technologies are either quite complex or designed to serve a very specialized market. Therefore, it is generally recommended that research in non-traditional water/wastewater systems receive a lower priority, at least until the benefits of water efficient technologies have been fully explored.

- Traditional Solid Waste Technologies - Modification of the structure to facilitate source separation of recycleable materials for collection from the home is the only area of traditional solid waste management which has been identified for further research.

- Non-traditional Solid Waste Technologies - Research on the potential for utilizing wastepaper as an auxiliary fuel should receive a high priority. The potential for more widespread use of the nutrient content of biodegradable solid waste in food production should be examined.

Traditional Water/Wastewater Systems

For most single family homes, the traditional water/wastewater system consists of a single potable water supply and a single wastewater management system. Potable water may be imported from a public supply or may be obtained on-site from a well or cistern. The homeowner must pay either utility bills or pumping costs for the delivery of pressurized water. The water supply is then divided into hot and cold, with heating generally accomplished through the use of an imported energy source. All water is wasted after a single use and the wastewater is collected in the household sewer. There are a large number of on-site wastewater treatment and disposal techniques used throughout the country, with the septic tank and soil absorption system being the most common.

There are many advantages to the use of a traditional water/wastewater system:

- There is no risk of accidental use of a nonpotable water supply, particularly by children or pets,

- A single potable water supply under pressure and a single gravity wastewater collection system minimizes the possiblity of mechanical cross-connections, and

- O&M costs are very low and there is minimal user participation.

The traditonal system is simple and marketable, and in most cases, works well. However, since it is not particularly efficient with regard to water use, and is not adequate on certain restrictive sites, possible improvements to the traditional water/wastewater system should be considered.

A lack of potable water or restrictions on wastewater disposal often prevent the use of a site for residential construction. Several areas for future RD&D efforts are presented below.

New Water Sources--

Traditionally, potable water is obtained either from a public system, where the water may or may not receive treatment, or a private on-site source which generally is untreated. Shallow private wells are a reliable water source in many areas. The use of surface water for individual water supplies is less common, and rain water collection is infrequently used. The design of low-cost reliable water supply treatment devices might increase the development potential of some currently restricted sites.

Flow Reduction--

The effectiveness of specialized low flow fixtures and appliances in reducing household wastewater flows by up to 50% has been well documented. However, additional demonstration would help establish credibility for this approach as a method of extending water supplies and reducing wastewater management requirements. In addition to using less water, flow reduction decreases water supply costs such as pumping, treatment and heating. Since less wastewater is generated, on-site disposal might be feasible on lots which are currently considered marginal. It is necessary to consider the impact such installations have on wastewater quality as well as quantity.

The importance of efficient devices in improving overall resource efficiency is clear. RD&D directed at improving the performance and reliability of very low flow fixtures and appliances should yield considerable benefit. Research should also be directed toward improving the market penetration of commercially available devices.

Septic Tank-SAS* Performance with Flow Reduction--

The performance of the standard septic tank-SAS under conditions of very low flow has not been widely monitored. It is presumed that treatment in the septic tank may improve because of the longer detention period, increased settling, and additional biological action. Further, very low flow toilets generally macerate the wastes, which may improve treatment efficiency.

Consumption of cold water can be cut more dramatically than that of hot water. Therefore, most researchers predict an increase in wastewater

*Soil Absorption System

temperature under very low flow conditions. The impact of such a temperature shift on treatment is not clear. The rate of bacteriological action will likely increase, which could positively affect treatment efficiency and accumulation rates for scum and septage, or could result in excessive gas generation and mixing of the septic tank contents, lending to increased suspended solids in the effluent. Ammonia toxicity might also result from increased biological activity in the traditional septic tank.

Studies of the above issues could prove valuable not only in providing guidance for the improvement of water/wastewater systems in new housing but also in the rehabilitation of failing systems.

Modifications to On-site Treatment--

The septic tank, the most common on-site wastewater treatment technology, is by no means perfect. With the introduction of a lower flow and much more concentrated waste, RD&D efforts should focus on development of improved septic tank designs. Modification could range from a simple redesign of a discharge fitting to a complete configuration.

The concept of septic tank management has received increasing acceptance in principle, if not in practice. All additional research in the field of septic tank modifications should include a detailed O&M component to identify minimum management requirements.

Alternatives to the septic tank for on-site wastewater pretreatment are primarily aerobic units which, when operating properly, provide somewhat better treatment. Research in this field should continue but at a lower priority since such units require additional imported energy, present a risk of mechanical failure and represent a significant increase in cost to the homeowner.

Improvement and Alternatives to the Soil Absorption Systems (SAS)--

In the vast majority of cases, on-site wastewater management system failures are actually failures of the soil absorption system due to hydraulic overload, solids carryover, or biological clogging. Additional RD&D could be directed toward modifications to the SAS system. Designs which have been promoted as reducing the risk of clogging from solid carryover or matting, such as alternating beds, should be evaluated. Innovations in SAS configuration should be encouraged with the goal of overcoming site restrictions.

One particularly attractive integration is the use of wastewater for subsurface irrigation of lawns and shrubs. There has been considerable research by members of the sanitary engineering community on the use of shallow soil absorption systems and evapotransportation beds. This research indicates that at least some grasses and shrubs thrive in situations where anaerobic effluents are introduced into the root zone. From another perspective, the American Irrigation Association has information on research involving root zone irrigation to maximize plant performance. Additional RD&D is needed to adapt these technologies to provide good plant growth as well as adequate wastewater disposal treatment.*

Despite drastic flow reductions, there may be areas of very tight soils, high groundwater, or bedrock where it would be desirable to eliminate wastewater discharge to the soil entirely. Lined ET systems have been designed which will perform this task, but they generally do not demonstrate the degree of flexibility desired due to dependence on favorable climate conditions and inability to handle peak loads. Solar assisted ET and mechanical evaporators should be investigated. At least one solar-assisted ET system has been installed in Pennsylvania.** A mechanical evaporator has been designed and a prototype has been tested under field conditions. Although the mechanical evaporator was not considered cost effective in processing conventional wastewater flows, its attractiveness is significantly improved for a very low flow household.

Implementation--

Many of these concepts are proven and even commercially available, but market penetration of improved water/wastewater technologies has been minimal due to institutional constraints and public acceptance barriers. Local and state officials, land owners, and home builders need to be provided with independent evaluations of the various fixtures and appliances along with information on how to encourage market penetration. Independent evaluations should assess performance, life cycle costs, and impacts on water supply and wastewater disposal requirements. It is possible to overcome these impediments through the development of educational programs presenting technical, environmental and socio-economic considerations aimed at the consumer, the home building industry and state and local regulators.

Strategies which local and state officials might use to encourage or require the installation of water efficient fixtures and appliances in all new construction should be developed. Such a study should examine the legal issues and the political and public acceptance aspects of the implementation strategies. The possible use of economic incentives, tax incentives, and exemptions from various regulations should also be analyzed.

Non-traditional Water/Wastewater Systems

Non-traditional water/wastewater systems include all systems which do not have a single potable water supply and/or a single wastewater management system. In this section, possible research programs will be discussed for three major categories of non-traditional water/wastewater systems:

---

*Nyadic of California, Windsor, California has installed approximately 50 systems. Septic tank effluent is delivered to drip irrigation systems. Shrubs and redwood trees are planted to increase ET.

**Norman Torkelson, Sundrine, Stockton, N.J., has installed a greenhouse ET bed in a solar home in Pennsylvania.

- dual water supplies
- segregated grey and blackwater systems
- wastewater reuse

Innovative non-traditional water/wastewater systems are presented in Table 1.

Dual Water Supplies--

In a limited number of locations, a nonpotable water supply is available, although a potable one is not. If it is desirable to build residences in these areas and impractical to import a potable water supply or collect rainwater, one may wish to consider a dual water system. The complexity and potential risks associated with such systems are related to the degree of contamination and the ability of the consumer to distinguish between the two supplies. Dual systems are often prohibited in private residences.

Solar stills and small water purification systems are commercially available which can be used to treat a sufficient volume for potable uses. Solar stills may prove to be a possible retrofit for residences in warm, dry locations whose water supply has been contaminated. Additional research in this area would have minimal impact on the overall improvement of resource efficiency in residential units.

Segregated Wastewater Systems--

There has been considerable research into systems which involve the segregation of the traditional wastewater stream into greywater and either water borne toilet wastes (blackwater) or waste from waterless toilets. As with the traditional water/wastewater system, there is a need for research to determine how the installation of water efficient fixtures will affect both the greywater and blackwater streams. Presumably the greywater would become more concentrated and have a lower temperature and the blackwater stream would become very concentrated. Because untreated greywater will become odorous if stored, it must either be treated or used immediately. Blackwater from a very low flush toilet, perhaps combined with food wastes, would have unique wastewater characteristics. Where greywater can be utilized beneficially it may be feasible to have a vented holding tank for concentrated blackwater. A more exotic option would be to attempt to capture methane from blackwater; however, our estimates indicate that the potential gains in terms of energy production could not justify the expense.

Numerous waterless toilets are currently being marketed using a wide range of processes from composting to incineration. These units seem more appropriate in commercial, recreational and industrial applications where large quantities of greywater are not generated. In the residential setting,

TABLE 1

NON-TRADITIONAL WATER/WASTEWATER TECHNOLOGIES

	POTENTIAL APPLICATION				CURRENT STATUS				COMPLEXITY RELATIVE TO TRADITIONAL WASTEWATER SYSTEM		
	New Construction and Rehab	New Construction	Constrained areas-supply	Constrained areas-disposal	Theoretical	Development	Demonstration	Commercial	Approximately the same	More Complex	Much More Complex
Non-traditional dual water supply			x				x				x
Solar still			x					x			x
Solar still and space heating combined			x		x						x
Rainwater collection			x				x		x		
Productive greenhouse		x					x				x
Greywater treatment for reuse			x	x		x					x
Blackwater holding tank		x			x				x		
Anerobic digestion w/ gas collection		x			x						x
Solar pasturization of greywater		x			x						x
Total water recycling system			x					x			x
Collection of filtrate from buried sand filters			x	x	x					x	

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further market penetration of the waterless toilet technologies is probably dependent on the development of greywater treatment and reuse systems.

Wastewater Reuse--

Greywater has been treated for several non-potable uses, for example, toilet flushing, surface irrigation (lawn sprinkling), laundry and outdoor uses. The problems encountered include treatment requirements, matching supply with demand, and provisions for overflows. The conclusion of this study is that water efficient technologies should always be implemented before wastewater reuse is considered.

A 100% residential water recycling system is currently on the market which treats a combined wastewater stream to potable quality. Such a system would be attractive only in areas of severely limited or nonexistent potable water supply. The technology, which is very complex and expensive, is limited to a very small segment of the residential housing market. Additional research in this area should be left to the private sector.

Subsurface irrigation, discussed above under options for improving traditional wastewater disposal practices, should receive a high priority in wastewater reuse research. Greywater subsurface irrigation in a productive greenhouse and septic tank effluent drip irrigation of shrubs and trees have both been demonstrated although neither has been well documented. Further research is needed to determine whether there are advantages to using greywater rather than total wastewater flow for subsurface irrigation. Because of the potential risks inherent in the use of any wastewater stream in irrigation, it is recommended that future research focus on irrigation of nonedible plants such as grass, shrubs, trees and flowers.

Traditional Solid Waste Technologies

Traditionally, solid waste has been collected on-site for periodic transport to an off-site disposal area. Frequently, collection is provided as a municipal or private service.

Garbage disposals have achieved widespread popularity because they eliminate the need to store food wastes on-site. Both traditional and nontraditional solid waste systems are presented in Table 2.

Many experts in the field of solid waste management recommend source separation of recyclable materials as a means to avoid the very difficult and costly task of separating recyclable materials from a mixed solid waste stream. Compartmentalized collection vehicles are available which would facilitate curbside collection of source separated residential wastes. However, the success of any such program would require that the homeowner take the time to separate the waste. Research could focus on the development of an architectural plan designed to make source separation of solid wastes and handling of multiple waste containers more convenient.

TABLE 2

SOLID WASTE TECHNOLOGIES

	POTENTIAL APPLICATION				CURRENT STATUS				COMPLEXITY RELATIVE TO TRADITIONAL WASTEWATER SYSTEM		
	New Construction and Rehab	New Construction	Constrained areas-supply	Constrained areas-disposal	Theoretical	Development	Demonstration	Commercial	Approximately the same	More Complex	Much More Complex
Source separation of recyclable wastes	x						x				x
Wastepaper for fuel	x					x				x	
Solar sludge drying		x			x						x

Non-traditional Solid Waste Technologies

Non-traditional solid waste technologies involve the utilization or disposal of all or a portion of the solid waste on-site. The primary components of the solid waste stream are paper, food, yard, and general waste. As highlighted in Section 5, there is considerable potential for the use of wastepaper as an auxiliary fuel source in an energy efficient home. Storage of the material would be feasible and the potential energy contribution is considerable. Additional RD&D is required to determine the actual heat output of furnaces and stoves burning waste paper and to assess the air quality impacts. Recent increases in the cost of heating fuel, which have motivated a number of homeowners to consider less convenient forms of fuel such as coal and wood, indicate that a technology which would safely burn wastepaper might be marketable.

Composting of food and yard wastes can provide nutrient recovery for use in the production of food as well as for landscaping. Composting is frequently practiced by avid gardeners but is often considered inconvenient relative to the use of a garbage disposal or curbside pickup. Development of a competitive composting unit might be advantageous where it is desirable to keep food wastes out of the wastewater stream.

Many of the waterless toilet technologies produce some form of solid residue. There are conflicting reports as to the safety of utilizing or disposing of these residues on-site. Because the potential nutrient contribution from toilet wastes is relatively small, when compared to the potential from food and yard wastes, research to confirm the safety of compost toilet products for on-site recycling should have a lower priority. This is consistent with the recommendation made above that research on waterless toilets for residential applications receive low priority.

SECTION 3

ASSUMPTIONS AND TECHNOLOGIES

INTRODUCTION

This section provides background for an interdisciplinary evaluation of alternative integrated residential utility systems. The various residential components including land, interior space, water supply, waste management, and energy systems are reviewed. The discussion focuses on the limitations of current conventional systems, the interdependence of the components, and future trends influencing technology selection.

In order to investigate the potential nature of housing in the year 2000 current housing trends were analyzed. In order to have a basis for evaluating novel integrated utility systems, a Baseline or year 2000 Market House was developed. Generally speaking, the Baseline or Year 2000 Market House represents 1980 state-of-the-art energy and water conserving technologies. The assumption is that 1980 state-of-the-art will be standard within 20 years.

RESIDENTIAL HOUSING COMPONENTS

Water Supply

Some form of water supply is essential for a residential unit and it is assumed that virtually all units being built over the next twenty years will have indoor plumbing with both hot and cold pressurized water systems. Most current systems consist of a single potable water source supplying specific fixtures such as toilets, washing machines and lawn sprinklers. Because of the risk of cross connection, dual residential water systems are presently rare.

Water sources vary greatly throughout the country and can be broadly grouped into five categories: water imported from a centralized system, on-site groundwater, on-site surface water, rain water collection and on-site distillation. Where available, centralized water supplies are generally considered both safer and more dependable. The availability of imported water has brought development to areas with either insufficient or contaminated water on-site. Only approximately 37% of homes with on-site wastewater systems utilize wells as the source of potable water. Virtually all homes on sewer systems are also served by a centralized water system and the remaining 63%

or more are served by centralized water systems.* Should this trend continue, a large percentage of the new homes to be built with on-site wastewater management systems will have a centralized water supply. The vast majority of the remainder will utilize individual on-site wells. The use of on-site surface water, rain water collection or distillation is relatively uncommon in this country, although the use of these sources could increase over the next 20 years.

Often, in the absence of a centralized water supply, development has only proceeded where groundwater of sufficient quality and quantity is available on-site. To prevent such water supply deterioration, which often leads to installation of a costly municipal system, many communities already regulate the density and nature of development in areas dependent on groundwater. Groundwater can be contaminated as a result of infiltration of contaminated stormwater runoff and seepage of septic tank effluents. Groundwater quantity can be depleted by over-pumping and reduced in discharge. Regulations, which require minimum lots of from 1/2 to 2 acres in New England and 10 acres or more in the Southwest, will clearly add to the cost of housing.

Alternatives to the traditional water system may help to reduce residential development costs in areas where groundwater is either:

- plentiful but of non-potable quality,
- of potable quality but scarce, or
- plentiful and of potable quality but very costly to pump.

Where quantity is the primary constraint, the use of water-efficient fixtures and appliances to reduce demand is very attractive. Where quality is the constraint, the use of a dual water system may be considered. Such a system may be ad hoc, in the form of bottled drinking water with the household water supply used for all non-cooking and drinking purposes, or formalized with dual plumbing. The use of dual water supplies always involves an increased risk that non-potable water will be consumed either through mechanical cross connections or misuse.

Waste Management Systems

A residence is a waste generator, producing general refuse, paper, yard wastes, food wastes, soap and detergent residues, dirt, human excrement, and combustion residues. These wastes leave the unit in one of three waste streams: wastewater, solid waste and waste gases. While some wastes are invariably part of a given waste stream, some (such as food wastes) can be diverted to any of the three. Table 3 summarizes the wastes generated in the

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*Water Supply-Wastewater Treatment Coordination Study, Report to Congress, U.S. EPA, Office of Drinking Water, August 1979.

TABLE 3

HOUSEHOLD WASTES AND EXAMPLE MANAGEMENT ALTERNATIVES

Waste	Management Alternatives	Waste Streams
General refuse	a. collection in refuse containers	solid waste disposed off-site
Paper	a. combustion	waste gases and flue ash
	b. collection as refuse	solid waste disposed off-site
	c. collected separately	solid waste recycled off-site for resource recovery
	d. used in composting or digestion	solid waste recycled on-site
Yard Wastes	a. combustion	waste gases and flue ash
	b. collection as refuse	solid waste disposed off-site
	c. used in composting or digestion	solid waste recycled on-site
Food Wastes--Garbage Disposal	a. discharge to wastewater treatment system	wastewater
Food Wastes--Garbage	a. collection with refuse	solid waste disposed off-site
	b. used in compost or digestion	solid waste recycled on-site
Dirt with soap & detergent residues	a. discharge to wastewater treatment system	wastewater
Human excrement	a. water carriage toilets	wastewater
	b. waterless toilets	solid waste generally disposed of off-site (some compost may be recycled on-site: waste may be in a sludge form)
Residues from fuel combustion		
-- cooking	a. vent into living space	gas
-- space heating	b. vent through flue	gas
Other liquid wastes such as cleaning supplies, paints, photographic chemicals	a. collection for disposal with refuse	solid waste
	b. treatment with greywater	wastewater

household, indicating the range of possible management alternatives and the resulting waste stream. The character of the resulting waste streams varies significantly depending on the methods for waste handling utilized. It is possible to divert a maximum amount of waste into the wastewater stream and, in fact, this is common practice with the use of water flush toilets and garbage disposals. It is also possible to shift toward the solid waste stream utilizing waterless toilets and garbage composting.

On-site disposal of residential wastes requires ultimate deposition into either the ground or the air. Surface disposal either on land or into water is generally not acceptable practice. The potential for recycling all or parts of waste streams as inputs into utility systems was an important concern of this project.

Wastewater--

It is a basic premise of this study to consider only on-site wastewater management systems. It is commonly accepted to use the term blackwater when referring to the wastewater generated by a water carriage toilet, the term greywater to describe all non-toilet wastewaters and the term combined wastewater to describe traditional systems in which grey and blackwater are mixed. This terminology becomes somewhat confused in that some dual wastewater systems have kitchen sink and dishwater wastewaters treated with the blackwater while others handle these wastes with the greywater.

Septic tanks with soil absorption systems (SAS) account for over 85% of the on-site systems currently being installed in this country. Due to their simplicity, code acceptance, and low energy requirements, it is likely that septic tanks and SAS will continue to be the preferred on-site wastewater management technology. A considerable amount of effort is currently being devoted to improving operations of these systems through proper siting, design, installation, and management.

Alternative methods of on-site wastewater management might be appropriate on parcels not meeting minimum requirements for septic systems for one or more of the following reasons:

- very high or very low percolation rates,
- high ground water table,
- close proximity to surface water,
- location in a sensitive aquifer recharge zone,
- close proximity to a drinking water source,
- steep slopes,

- shallow depth to bedrock, and
- insufficient area.

Alternatives to the standard septic tank and SAS field fall into five categories:

- the basic septic tank with an alternative disposal system such as mounds, evapotranspiration fields or holding tanks;
- improved treatment processes such as buried or recirculating sand filters, aerobic treatment processes, or disinfection prior to disposal, possibly to the land surface or surface water;
- significant reductions in the hydraulic loading through water conservation;
- segregation and separate processing of blackwater and greywater;
- complete recycling of a combined wastewater stream on-site.

Many of these alternative technologies are used in retrofit situations where the home is already in existence and health officials are willing to relax regulations to permit continued occupancy of the structure. Appendix A provides an evaluation of alternative waste management techniques.

Solid Wastes--

Most residential units in this country have access to centralized solid waste management facilities, although proximity to these facilities may dictate the degree to which residents wish to use them. For example, in many northern rural areas, food wastes are simply stored outside (frozen) during the winter months to avoid frequent trips to the landfill. Where the resident must transport solid wastes to the disposal facility or must pay for pickup of the load, there is an incentive to recycle solid waste on-site to the maximum degree possible. Where weekly curbside pickup is provided as a municipal service, the incentive is to utilize this service to the maximum.

On-site solid waste management technologies are limited to forms of burial, combustion, and recycling. Burial of solid waste on a residential lot would not generally be considered acceptable practice and will not be considered as an option. Open burning of general refuse is outlawed in many areas because of resulting air pollution. Controlled high temperature incineration is not widely used at this time although its potential is examined in Section 5 where the use of waste paper as a fuel source is also examined. Recycling of the nutrients in food and yard wastes through composting may reduce the need to purchase fertilizer. Source separation is required if recyclable materials in solid waste are to be utilized either on or off-site.

Waste Gases--

By and large, all residential waste gas streams are simply vented to the atmosphere. Heat recovery from waste gases has received some attention. Heat can be recovered from furnace and stove exhaust gases and is generally used to either provide additional space heating or to preheat combustion gases. As the insulation of homes increases, the number of air changes per hour drops. To reduce the risks of indoor air pollution and minimize heat loss, heat exchangers will be increasingly installed in residential ventilation systems.

Energy Systems

Energy input to a residence is used for a large variety of tasks, such as: cooking, space heating and cooling, mechanical power, water heating, lighting, and operation of appliances and electronic equipment. The energy systems which can be used to perform these various tasks are summarized in Table 4. It is safe to assume that virtually all residential units built in the next twenty years will have an electrical system. However, electricity is not the best form of energy for all of the tasks which are performed within the home.

The term "energy conservation" really refers to fuel conservation. The essence of energy conservation is maximizing the efficiency with which a fuel is used to do a particular task. This efficiency should be measured both by the total amount of source energy used in a process (the oil consumed at the power plant or by the furnace flame) and also by the degree to which that energy has been degraded in its usefulness. It is most efficient to match the quality of an energy source to its end use as closely as possible. Electricity is considered a very high quality form of energy because of the wide range of high quality work that it can perform. Heat, the form into which all energy eventually degrades, is the lowest quality form of energy.

Matching the quality of an energy source to its end use increases the possibilities for "cascading" the energy, or extracting work from the energy at more than one level. Electricity can be used for mechanical power, and then the heat generated by the process can be used for a second purpose. Lower forms of energy, such as heat, can be used to perform a higher grade task, such as mechanical work, however, this requires concentrating and upgrading the energy and so the process tends to be quite inefficient. If, however, the low grade energy is abundant and would otherwise be wasted, such inefficiencies can sometimes be justified. An example would be using the heat captured with a solar collector to drive a heat engine.

When matching an energy source to an end use, time availability and distribution should also be considered. Chemical energy such as natural gas is easily stored and transported, whereas the mechanical energy generated by a wind turbine is difficult to save until needed and difficult to transfer over long distances. For grid electricity and piped natural gas, the utility

TABLE 4

ENERGY SYSTEMS

Task	Commonly Used Energy Sources
Cooking	Electricity,* gas, wood, coal
Space Heating	Electricity, gas, wood, oil, coal, solar
Cooling	Electricity, solar, gas, on-site heatsinks
Pumps (and other mechanical)	Electricity, gas, wind
Lighting	Electricity
Electronic (TV, computer, stereo)	Electricity
Refrigeration	Electricity, gas
Clothes Drying	Electricity, gas, solar
Water Heating	Electricity, gas, oil, solar
Machines and appliances	Electricity, gas, oil

* Electricity can be imported or generated on-site with wind generators, low head hydro, or photovoltaics.

company must stockpile and provide energy on demand. All other forms of residential energy require some mode of on-site storage. Thus the base and requirements of storage also becomes a prime criterion.

Innovations in energy systems are discussed briefly below. For more details on specific systems refer to Appendix A.

Electricity--

The actual source of electrical energy generation does not directly determine how that energy is used. Rather, it is the cost structure and the availability of the electricity, however generated, that has the most significant impact on strategies for its use. Expensive electricity will tend to reduce overall demand and promote conservation whether it is generated at a remote power plant or an on-site wind turbine. If electricity is more available (i.e., cheaper) during one part of the day than another, whether because of utility rate structures or peak wattage of a photovoltaic array, people will tend to shift demand to the cheaper times.

The issue for future projections is not so much the source of electrical generation but the predicted cost structure and availability. Photovoltaics and wind generators currently show great promise. Wind generators are already cost competitive with central utility companies in many parts of the country, particularly those with high electric rates and/or constant high winds. It is likely that photovoltaics will be integrated with flat-plate active solar collectors used for space heating, eliminating competition for solar exposure. Thus, the impact of photovoltaics on building technology will be no greater than typical solar heating systems.

Energy Conservation--

Energy conservation is currently the most pressing issue in the field of interior space construction. The most significant strategy for energy conservation, anywhere in the country, has proved to be increased insulation levels which reduce energy losses through the skin of the building. Typical levels of insulation have been increasing at a rapid rate, responding to the rise in the energy prices. In addition to thickening exterior walls, greater attention is being paid to maintaining the integrity of the insulating envelope by avoiding any penetrations by plumbing, electrical, or other mechanical systems.

The need to conserve the energy used for heating and cooling is also likely to create an impetus for smaller, more compact structures. Regional solutions are likely to gain hold as building design responds more to the local climate. For example, adobe construction has regained popularity in New Mexico and Arizona, where it is a native material requiring comparatively little energy to fabricate. The thermal properties of adobe help to moderate the wide daily temperature variation found in a desert region. Similarly, earth-sheltered and underground houses are proving to have thermal advantages in Minnesota and other mid-western states where earth temperatures can help to dampen the effects of dramatic seasonal temperature swings.

A second area critical to energy conservation is the control of air infiltration into buildings. Reducing the amount of air that naturally leaks through the cracks and pores of a house can save a major amount of energy for both space heating and cooling. Until recently, one air-change per hour was considered representative of good quality construction. Tighter construction techniques, along with plastic vapor barriers and careful caulking have taken experimental houses down to one-tenth of an air-change per hour. To maintain such low infiltration rates, plumbing and mechanical systems must be separately vented with outside air or have an air-to-air heat exchanger connected to the exhaust. It is likely that all forms of ventilation will be much more carefully controlled in the future. Use of air-to-air heat exchangers to provide sufficient air-changes to reduce risk from indoor air pollution may become standard practice in extremely tight structures.

Solar Heating--

Solar heating has gained more attention in recent years. Dramatic house forms with steeply pitched roofs and vast expanses of south glass have been built. However, while solar heating requires careful design, radical departures from traditional house-forms and construction is not necessary, as has been amply proved by many designs and documented by various Department of Energy, Housing and Urban Development, and state solar commercialization programs. By first reducing energy requirements with insulation and other energy conservation techniques, the area required for solar collection is also reduced. One hundred percent solar heating is not generally considered a reasonable goal, because incremental costs increase dramatically as one approaches 100%. Instead, a 30% to 70% solar contribution currently seems to be the possible range for most of the country. A "back-up" heating system is thus necesary to meet the remaining heating load.

For either an active or a passive solar heating system, the need for thermal storage must be appreciated. Solar energy can directly meet the heating load of a house while the sun is shining; however, two-thirds of an average heating load occurs during the night time. Thermal storage materials allow the excess solar heat available during the day to be stored until needed later, so a much greater percentage of the houseload can be met with solar energy. Storage materials have typically been rockbeds, water tubes, and special masonry construction, all of which are quite space consuming. Phase change systems, such as eutectic salts, are being developed which may be able to reduce thermal storage space requirements.

Solar Cooling--

Active solar collectors have been used to supply the heat for absorption cooling systems. However the high temperature heat required and the large capital costs of the system have not made active solar cooling an attractive option for individual residences. A dessicant cooling system which is compatible with the low temperature flat plate collectors shows some potential for residential applications. Currently, a good deal of research is being conducted on passive cooling methods, commonly taking advantage of evaporative cooling principle and/or night-sky radiational cooling. Both of these passive approaches tend to involve fairly major structural modifications. Solar cooling research in general lags far behind solar heating technology and is unlikely to have widespread application in the next 10 years.

Housing Trends

Land Lot Size--

The quality of the lot greatly influences the character of the new residential housing unit. Access to centralized systems for the collection of wastes (sewers and refuse pickup), water supply, grid electricity and piped natural gas are key factors in the selection of utility systems. Where sewer service is not available, the ability of the lot to accomodate a traditional on-site wastewater management system is often the overriding element in determining the development potential of the parcel. As more alternative on-site utilities are used, characteristics of the lot, which until now have received little attention, will become significant. For example, solar exposure will become a key in determining the desirability of a site for solar heated or powered housing units. Conversely, the use of alternative wastewater management systems may reduce site limitations.

Site improvements such as roads, utilities, driveways, and landscaping are becoming a very significant factor in housing costs and are likely to be a motivating force for denser development in the future. According to the National Association of Home Builders (NAHB), land costs, including site improvement, currently comprise 40% of the overall house cost, where ten years ago they comprised only 17%.* The NAHB sees reducing land development costs as the most promising approach to bringing overall housing costs down. One approach is to increase densities, reducing the length of roads and service lines. Another strategy is to limit the types of services brought to the house. The NAHB is strongly promoting cluster development, claiming it reduces not only development costs but also maintenance costs borne by the town, thus benefiting the homeowner through reduced taxes. However, cluster development may pose space problems for the use of individual on-site septic systems, making the use of small-scale community wastewater management systems very attractive.

The national average lot size is currently less than 1/4 of an acre, and in the western states the average lot size is getting very close to 1/6 acre. Furthermore, average lot size has been steadily decreasing at an annual rate of 3%.** Even outside of the Census Bureau's Standard Metropolitan Statistical Area--SMSA's, the average lot is significantly below 1/3 acre.

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*Conversation with Richard Gauche, Land Use Department, NAHB, May 21, 1980.

**Eleventh Annual Report on the National Goal, U.S. Department of Housing and Urban Development, 1980.

In addition to smaller sites, it is likely that housing units will be built on increasingly marginal land. The easiest land on which to build is often also the best agricultural land. Intense development pressure on rural lands has caused a net loss of prime agricultural land. This loss is currently estimated at about one million acres per year, or over four square miles per day.* In an effort to slow this loss, state legislation is beginning to emerge which is designed to protect agricultural land from development, with zoning ordinances, tax laws, or regional plans. Such laws are likely to force development into areas where construction and wastewater disposal costs are high, such as hilly or rocky sites, generally driving up the price of housing.

Despite pressures for greater density, the single family housing is likely to continue to be the most significant element of the U.S. housing market. Single family detached houses comprised approximately 70% of all housing units built in 1978, with multi-family units at 20% and mobile homes at 10%. This pattern has basically persisted for the last 30 years. It is interesting to note, however, the importance of custom-built, single family housing versus market housing. Inside of the SMSA's, i.e., in urban areas, custom-built houses comprised only 25% of the total housing starts in 1978, whereas outside of the SMSA's they constituted 63%, a clear majority.**

It is the areas outside of the SMSA's that are most important for this study. Over one-half (51%) of the housing outside of the SMSA's use some form of an on-site waste treatment system. Furthermore, the majority of on-site treatment systems (61%) exist outside of the SMSA's.*** The importance of custom built housing outside of SMSA's suggest a greater latitude for specially constructed and alternative utility systems than might be the case with market housing, where the pressures are to build identical systems regardless of site variations or inhabitants' preferences.

House Size

For the last ten years or so, most housing analysts have been making the prediction that houses would get significantly smaller. They have argued that the rising costs of development, of building materials, and of energy would force smaller houses to become acceptable to the American public. As a corollary to this argument, they have predicted that attics, basements, garages and other secondary and storage spaces would tend to disappear in favor of living spaces.**** Such predictions imply that mechanical systems would also have to become more compact to conserve space for other purposes. For example, the bulky furnace and water heater in the basement will have to shrink to fit into a small utility closet.

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*Environmental Quality, The Ninth Annual Report of the Council of Environmental Quality, December 1978.

**Characteristics of New Housing, 1978. Construction Reports C25-78-13, U.S. Bureau of the Census.

***Annual Housing Survey 1977, Series H-150-77 part A, U.S. Bureau of the Census.

****See interviews and references in Appendix C.

These predictions, however, have so far been wrong. Except for mild fluctuations in the late 60's, and after the 1974 recession, houses have been getting larger every year. The average size of the American house in 1979 was 1750 square feet, the largest yet. Furthermore, the number of houses with garages and basements has also been steadily increasing.* It would seem that this trend cannot continue indefinitely, and that eventually, certainly within the next decade, the trend will reverse and houses will start to get smaller.

Substitutions of other less expensive housing types, such as apartments or mobile homes, for the single family may distort the figures, keeping the average size of the single family growing while the size of average housing units of all types decreases. The average size of an apartment has been 3% smaller every year, decreasing from 1021 square feet in 1974 to 902 square feet in 1978.** And while mobile home units have been getting larger and more elaborate, it can be argued that they are taking over the market for low income housing.

Mobile Homes and Prefabricated Housing

Mobile homes have maintained a significant share of the housing market for the last twenty years, varying between one-in-six to one-in-three of all single family units sold in a given year.*** The average selling price of a single wide unit in 1979 was $8,800, and a double-wide, $19,999.**** With transportation, hookup and land charges adding perhaps another 50%, the cost of a mobile home is still remarkably less than the lowest cost single family detached house.*****

Mobile homes, much more than other forms of pre-fabricated housing, seem to have become successful at reducing the cost of housing through industrialization. While manufactured housing companies, which prefabricate the framing and skin components, have approximtely the same share of the market as mobile homes (20% in 1979),* they have not been able to provide cost advantages, often costing as much or more than a custom built home. Their primary advantage has been in the speed of delivery and construction time rather than cost. Mobile homes** have had a significant cost advantage over other forms of prefabricated housing in that they are built to their own uniform national code and thus are not hampered by local code variations. Other forms of prefabricated housing have to satisfy the local code of any area to which they might be shipped, and thus must be built to the highest standards, making them less competitive in areas with less stringent housing codes.

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*Characteristics of New Housing, 1978. Construction Reports C25-78-13, U.S. Bureau of the Census

**Op. cit.

***Housing Starts, February 1980, Series C20-80-2, U.S. Bureau of the Census.

****Interview with Walter Burning, President, Manufactured Housing Institute, Washington, D.C., 5/16/80.

*****This does not consider the overall financial effects of a shorter lifetime for mobile homes or different financing terms from a single family house.

Prefabricated Components

Although an enormous amount of attention and research effort was devoted to industrializing the housing industry during the 60's and early 70's (for example, HUD's Operation Breakthrough), relatively little change has occurred in that area. For numerous reasons, prefabricated housing systems were not found to be competitive with the traditional site-fabricated construction industry. Instead, breakthroughs in costs and efficiency were achieved with smaller prefabricated building components, such as roof trusses, pre-assembled window and door units, or exterior wall sheathing systems. Larger assemblies such as whole bathroom units were generally too constraining. They could not be modified to satisfy local conditions or customer preference.

Major advances have also been achieved in the use of on-site power tools and other labor saving devices. There has been a general trend towards increasing productivity, while also lowering the overall skill level, of the residential construction worker. This trend has also been reinforced by the importance of owner-builder and do-it-yourself markets. Indicative of this trend is the replacement of lath and plaster walls by large sheets of gypsum board installed with power driven screws, or the replacement of copper and cast iron plumbing by plastic pipe, which can be worked with hand tools and easily joined with a solvent.

Materials

Wood is likely to continue to be the single most important residential building material. It is easily worked, cut, nailed and repaired. It is a renewable resource, and compared to plastics, metal or concrete, requires much less energy for processing. A scarcity of high quality wood, however, is likely to promote the increased use of "wood products" such as plywood, particle board, oriented-strand board and other composite wood materials that can be manufactured from small, low-grade trees. Treated wood foundations may possibly become more common because they can free construction from weather constraints, eliminate an extra crew from the site, and are easy to insulate.

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*Interview with Walter Ekblaw, President of Scholz Homes, Inc., Toledo, Ohio, 5/16/80.

**Mobile homes, especially the two-three million located in mobile home parks, offer an interesting side note to this project. Hookup to nearby town services, especially the sewer system, is often a major political battle and creates formidable barriers in locating a mobile home park. The average population of a park is about 150. The comparatively high density of the parks (about seven units or 16 people per acre) and their private ownership make them particularly amenable to small community-scale integrated systems.

Concrete and other masonry systems are likely to play a much smaller role in residential construction in the future. They are heavy, and thus expensive to transport. They are labor-intensive and extremely energy-intensive materials, which may put them at a cost disadvantage.

Plastics have made enormous inroads into residential construction. Plastic has the advantage of being easily molded into intricate shapes, such as window frames, and its durability and non-corrosiveness make it useful as a finish material. The rising cost of petroleum will probably make plastics much less cost-competitive in the future than they are now, making the all plastic house very unlikely, but they will remain important for the jobs they do well.

Information Systems

A thermometer and a thermostat are both examples of residential information systems; one simply displays data while the other utilizes the data to operate a mechanical device such as a stove, furnace or freezer. Information systems consist of various components including sensors, displays, information processors, and control devices.

Displays such as thermometers and clocks are so common as to be considered essential. A more recent addition to this category would be the smoke or heat alarms. Information may also be reported to a remote location such as the service center, fire department or police department.

Linked sensors, information processors and control devices can produce an automatic control system to relieve the resident of repetitive tasks. Systems made up of sensors which connect directly to control devices are commonly used in homes today. Thermometers, automatic timers, and photoelectric cells are sensors which can respond to environmental conditions and can either mechanically or electrically initiate a control device. There is ongoing research to find more application for this simple type of information system, for example, phase change hinges which would automatically open and close insulating shutters.

Perhaps the greatest innovations in the use of automated controls will rely on the microprocessors which permit the use of a much wider range of information. Information such as temperature, wind direction and velocity, remote water levels, pH, etc., can be analyzed by a microprocessor with various control actions being initiated when readings meet a predetermined level. The sophistication of information systems controlling heating and cooling systems will definitely increase, particularly in the control of passive and active solar systems.

Traditionally, information systems have not been used to control on-site wastewater management technologies. With the advent of more sophisticated systems such as aerobic systems, pressurized effluent distribution systems, etc., there has been some increase in the use of information systems. Some of the currently available alternatives employ very sophisticated information systems to ensure proper operations. Information systems could also be used to improve operation of the traditional septic system by informing the resident when the tank should be pumped, automatically alternating effluent to different drain fields and so on.

The key to improving the use of information systems in the residential setting appears to be the development of low cost, reliable sensors for automatic control of a mechanical or electrical unit.

Baseline Year 2000 Market House

Early in the study two points became clear. First, there is no typical U.S. house. Regional preferences, traditions, climates, materials, and costs as well as the availability of resources such as water, land, and energy all influence the character of a residential unit. Second, to evaluate alternative utility systems it is necessary to compare their projected performance against some standard. The Baseline House has been developed for this purpose.

Based on the findings of the research, the resource requirements of a hypothetical year 2000 market house were developed and are presented in Table 5. In most instances this Baseline Year 2000 Market House assumes 1980 state-of-the-art technology, based on the assumption that twenty years is sufficient time for market penetration. For comparison, the resource requirements for a similar Year 1980 Market House are also presented in Table 5.

The hypothetical house is a single family, two story, three bedroom, detached wood frame structure with a slab foundation. In calculating resource requirements, the occupancy level is assumed at four persons. For purposes of calculating space heating requirements a relatively severe climate (Boston) has been selected.

The annual resource requirements and waste production figures for the Baseline House are presented in Figure 3. A similar figure (Figure 4) presents the same data for the Year 1980 Market House.

These baseline figures are based on professional judgment and are meant only to provide a relative measure against which various innovative utility systems can be evaluated. In considering the impact of a potential utility system in a specific location, a more detailed site specific analysis should be done.

TABLE 5

Resource Requirements for
Baseline Year 2000 Market House
and
Year 1980 Market House

Resources	Year 1980 Market House	Baseline Year 2000 Market House
Space: land	1012 m^2 (1/4 acre)	1012 m^2 (1/4 acres)
living	140 m^2 (1500 ft.^{2})	140 m^2 (1500 ft.^{2})
heated utility	14 m^2 (150 ft.^{2})	14 m^2 (150 ft.^{2})
unheated utility	none	none
Space Heating[1]		
o Load Reduction:		
ceiling insulation	R-19	R-30
wall insulation	R-11	R-19
window insulation	double glaze	double glaze w/R-4 night insulation
slab insulation	none	none
airchanges per hour		0.6
night setback	none	7°
internal heat gain	53,000 BTU/day	53,000 BTU/day
o Heat Load	99x10^6 BTU/year	43.9x10^6 BTU/year
o Solar Heating System	none	19 m^2 (200 ft.^{2}) passive 28 m^2 (300 ft.^{2}) active collectors mounted at 45° on South facing roof 22.6x10^6 BTU/year
o Non-Solar Heating requirements	99x10^6 BTU/year	21.3x10^6 BTU/year
Water Supply[2] (for interior use only)		
Source	Municipal	Municipal
Average daily requirements		
Total	787 l (208 gal)	408 l (108 gal)
Hot	265 l (70 gal)	95 l (26 gal)

TABLE 5
(continued)

Water Heating		
	40 x 10^6 BTU/year	Solar heating system plus 2.0x10^6 BTU/year auxiliary requirement
Cooking[3]		
gas	12x10^6 BTU/year	6x10^6 BTU/year
Grid Electricity[4]	4128 kwh per year	3600 kwh per year
Wastewater Management		
	4500 l (1200 gal) single compartment septic tank gravity flow to soil absorption field	6000 l (1500 gal) two compartment septic tank, 1 dose/day uniform distribution soil absorption field
Solid Waste Management[5]		
Hauled off-site		
food	476 kg 1056 lb	476 kg 1056 lb
yard	538 kg 1184 lb	538 kg 1184 lb
paper	968 kg 2130 lb	968 kg 2130 lb
other	866 kg 1918 lb	866 kg 1918 lb
Total	2848 kg 6278 lb	2848 kg 6278 lb

TABLE 5

NOTES

1 Space and water heating load requirements and solar contribution calculated using Passive F-CHART computer program with stated assumptions.

2 Based on figures from: R.L. Siegrist, R. Woltanksi, and L.F. Waldorf, "Water Conservation and Wastewater Disposal," ASCE 5-77. Assume consumptive use is negligible.

Year 1980 House:	5 gallon flush toilet, no garbage disposal, standard faucet and shower fixtures
Baseline Year 2000 House:	Based on use of 2 liter flush toilets, no garbage disposal, "suds-saver" washer, aerators and air assist showerheads.

3 Boston Gas Company reports average monthly consumption for cooking at approximately $.5 \times 10^6$ to 2×10^6 BTU's; assume 1×10^6 BTU/month for year 1980 Market House and $.5 \times 10^6$ BTU for Baseline Year 2000 House

4 Arthur D. Little, Inc., "Project Independence Task Force, Residential, and Commercial Energy Use Patterns 1980-1990" and Northeast Utilities, "Some Helpful Hints on How to Conserve Energy."

Take Arthur D. Little numbers for 1980 annual usage (Kwh/unit) and subtract hot water and cooking (which are covered by other fuels) and freezer (which is projected the least common load in 1970 after hot water) and total annual usage is 4,133 Kwh/year for a family of four, or 344 Kwh/month. If you then assume 10% conservation over the 1970 figures to allow for more efficient appliances the figure is 309 Kwh/month as a projection for Year 2000.

Or, take the Electrical Energy Association numbers for the appliances checked, and assume 550 watts of lighting for 4 hours per night for 360 days/year at about 800 Kwh/year for lighting, total yearly use is 3,760 Kwh/year or 313 Kwh/month. With 10% conservation for the Year 2000 use is 281 Kwh/month.

6 Volume figures:

J. Hudson and M. Alford, "Projections of Solid Wase Management Costs." Paper in support of the Resource Conservation Committee, 1979.

Distribution figures:

Franklin Associates, Ltd., "Analysis of Environmental and Economic Impacts of Waste Reduction Procedures and Policies," 1977.

Figure 3

BASELINE HOUSE

YEAR 2000 MARKET HOUSE

ANNUAL RESOURCE BALANCE

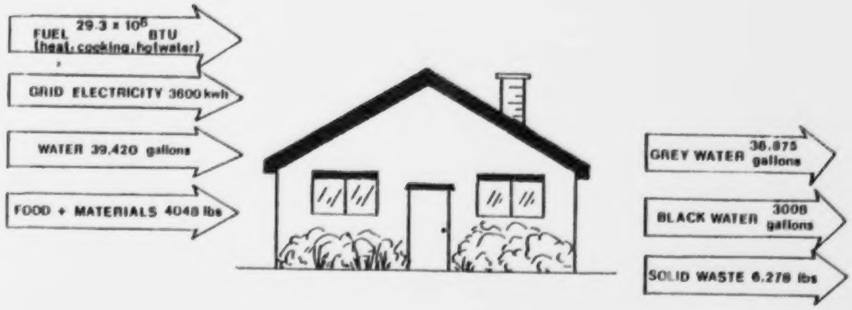
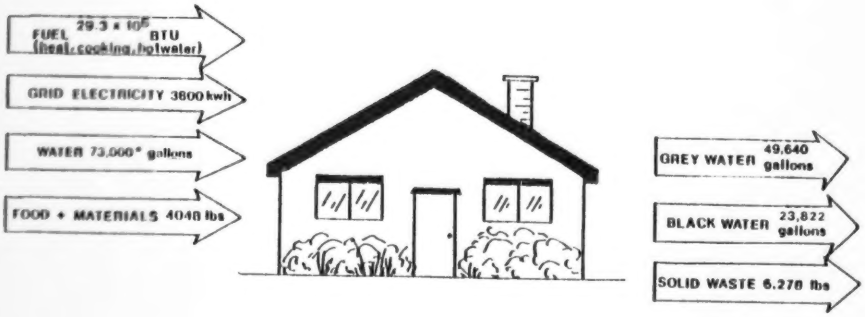

FUEL 29.3 x 10⁶ BTU (heat, cooking, hotwater)
GRID ELECTRICITY 3600 kwh
WATER 39,420 gallons
FOOD + MATERIALS 4048 lbs
GREY WATER 36,875 gallons
BLACK WATER 3008 gallons
SOLID WASTE 6,278 lbs

Figure 4

YEAR 1980 MARKET HOUSE

ANNUAL RESOURCE BALANCE


FUEL 29.3×10^5 BTU (heat, cooking, hotwater)
GRID ELECTRICITY 3800 kwh
WATER 73,000* gallons
FOOD + MATERIALS 4048 lbs
GREY WATER 49,640 gallons
BLACK WATER 23,822 gallons
SOLID WASTE 6,278 lbs

*for internal uses only

SECTION 4

ISSUES OF INTEGRATION

INTRODUCTION

Alternative utility systems are generally installed for one of two reasons: either because they can provide the same service at a lower cost or because they can perform where the conventional system cannot. Even when an alternative system meets one of these two criteria, market penetration takes a significant period of time, for several reasons:

- reluctance to make necessary capital investments;
- poor distribution of information;
- unwillingness to accept a different utility;
- unwillingness to accept different O&M responsibilities, and
- institutional and regulatory barriers.

The issues which should be considered during the development of any integrated utility systems are presented below.

REDUCING RESOURCE CONSUMPTION

Whether the overall objective of installing an alternative system is to reduce costs or to provide improved performance, such systems usually involve reducing consumption of a scarce resource. The resources of concern are imported energy (electricity, natural gas, or oil), water, food, and waste disposal capacity. While there are those that advocate the conservation of these resources regardless of availability, the typical consumer is not likely to conserve a plentiful resource.

The simplest method to reduce resource consumption is simply to do with less. This usually requires minimal capital expenditure and is often the first step taken. For the sake of this discussion it is assumed that wasteful uses have been eliminated, and that a physical change in the utility system is required if additional reductions are to be made.

Three different approaches can be taken:

- o improve the efficiency of the equipment;
- o recycle the resource on the site;
- o cascade the resource from higher to lower use;

Improved efficiency can often result in significant resource savings. By using less in the first place, there is less waste, and relatively little to recover and reuse. Highly efficient systems are often simpler than recovery systems, and as a result, tend to be more cost-effective.

A resource is generally degraded by use. For example, water is contaminated with impurities or energy becomes more defuse. In order to recycle these resources for the same use, the impurities must be removed from the water and the energy must be concentrated. In either case, energy must be expended before the resource can be recycled.

The concept of cascading involves the reuse of a resource in its lower energy or contaminated state. Total or partial recycling is more common in water systems while cascading is more applicable in energy systems.

The case of domestic hot water can provide an interesting example. Compare a water efficient household (House I) to one with standard water usage and greywater heat recovery (House II). The House II might require 378 liters/day (100 gallons/day) of hot water for dishwashing, laundry and bathing. The initial load would be approximately 110,000 BTU/day. With reasonable assumptions for the heat available in the greywater and the efficiency of the heat exchanger, 50,000 BTU/day of energy might be available for recovery reducing the overall load to 60,000 BTU/day.*

By comparison, House I makes more efficient use of hot water through the use of commercially available devices and user participation. Lowering the temperature set point, using low flow shower heads, cold water laundry and alternate day dishwashing, the load can be reduced to 95 liters (25 gallons) of hot water a day.** This would require approximately 27,000 BTU/day or 45% of the requirements in House II.

Not only does improved efficiency reduce consumption of resources, it may also reduce the initial capital investment. In the above case, the House II greywater recovery system would require a greywater storage tank, a double walled heat exchanger, and an additional pump with controller, all of which must be placed in heated utility space. The cost of this system would be approximately $400 in materials and $400 in labor. The House I hot water system can be achieved with minimal capital investment for low flow or very low flow showerheads.

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*See Section on greywater heat recovery

**See Base Case House

A common yardstick for comparing different energy saving options is the cost-to-performance ratio. It is defined as the ratio of the incremental initial cost of an option to the first year energy sayings in millions of BTU. The House II greywater heat recovery cost-to-performance ratio would be approximately $\$44/10^6$ BTU as compared to the House I system with a cost-to-performance ratio of about $\$1/10^6$ BTU. Similarly, one is better off buying and installing maximum energy efficient electrical appliances rather than trying to recapture the waste heat from inefficient appliances for space heating.

A similar comparison can be made between very low flush toilets using potable water and recycling toilets using greywater. Since conventional toilets utilize approximately 19 liters (5 gallons) of potable water, the concept of cascading the water from a higher use (bathing and laundry) to a lower use (toilet flushing) has led to the development of the greywater recycling toilet systems. These systems, although not common, are commercially available and are expected to reduce potable water consumption by 60 lpcd (16 gpcd). Very low flush toilets can reduce potable water consumption by up to 53 lpcd (14 gpcd).

While the components for a home built recycling system can be purchased for 1 to 1 1/4 times the cost of a very low flush system, the commercially available systems are up to 5 or 6 times as costly. The recycling system has several more components including pump, storage/settling tank, pressure filter and disinfection unit. In additon to consuming heated utility space, and increasing operations and maintenance for filters and disinfectant chemicals, the number of components increases the risk of failure. The very low flush toilet system provides the same service, requires simpler plumbing, takes up less space and is mechanically simpler.

MARKET INCENTIVES

When allocating a scarce resource, one should attempt both to utilize efficient equipment whenever possible and to match the quality of the resource with the task to be accomplished. The extent of the particular resource scarcity and the relative scarcity of other resources will both be factors in the selection of alternative utility systems. For example, in the extreme case of high energy costs and plentiful potable water, there should be efforts to conserve hot water but no efforts to reduce water consumption beyond the point where additional pumping or treatment is required. On the other extreme would be an abundant source of energy and no potable water. In this case the installation of a 100% water recycling system might make sense.

The situations in which a builder might have sufficient incentive to install an alternative utility system can be divided into two categories, those where one hopes to reduce the costs of performing the same task and those where the alternative system can perform where a conventional system cannot.

Cost Reductions

Cost saving alternative systems are generally those which reduce demand for expensive resources such as oil, natural gas, electricity, water or food. In a few cases such systems could be used to reduce the cost of handling wastes. To reduce the amount of resources imported to the site, the owner has three choices:

- use the resources more efficiently to perform the same level of service (insulation, more efficient motors, eliminate leaks, or recycle);
- produce the resource on-site or substitute an alternate resource (gardens, solar space heating, wind turbines, recycling greywater, etc.);
- do with less (reduce indoor temperature, turn off lights, hang clothes out to dry, lower water quality standards, etc.)

Improved Performance

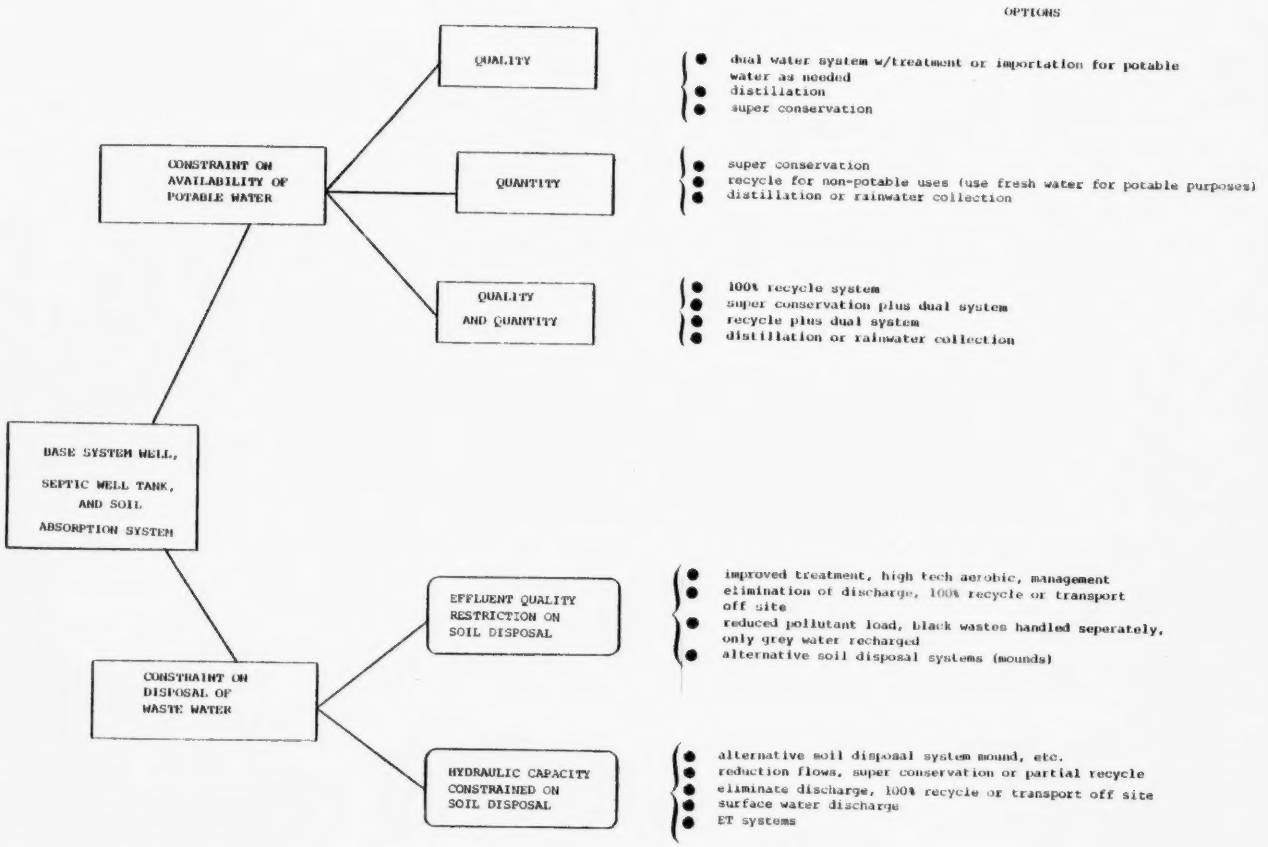
Alternative utilty systems are likely to gain greater market penetration if a definite improvement in performance can be demonstrated. The degree to which the performance is judged to be superior to conventional practice will vary greatly depending on local conditions. Site constraints which limit access to or performance of traditional utilities may favor alternative utility systems which would be non-compatible in the average home.

Site Constraints

When the owner of a parcel of land cannot build using conventional systems, alternatives become very attractive. This type of constaint tends to fall more heavily on the provision of water supply and wastewater management, although energy systems may be involved. A remote location with difficult access to grid electricity may find on-site electrical generation practical. Figure 6 summarizes the typical constraints to the provision of water and wastewater services, and suggests alternative systems which may permit construc,ton on such sites.

Constraints on Potable Water--

In areas with no access to municipal facilities and insufficient potable water on-site, there has been relatively little building. Availability of an adequate water supply is an essential criterion for residential development. There are, however, different types of constraints on potable water supply and a number of alternative water/wastewater utilty systems.


BASE SYSTEM WELL,
SEPTIC WELL TANK,
AND SOIL
ABSORPTION SYSTEM
CONSTRAINT ON
AVAILABILITY OF
POTABLE WATER
QUALITY
QUANTITY
QUALITY
AND QUANTITY
CONSTRAINT ON
DISPOSAL OF
WASTE WATER
EFFLUENT QUALITY
RESTRICTION ON
SOIL DISPOSAL
HYDRAULIC CAPACITY
CONSTRAINED ON
SOIL DISPOSAL

OPTIONS

- dual water system w/treatment or importation for potable water as needed
- distillation
- super conservation

- super conservation
- recycle for non-potable uses (use fresh water for potable purposes)
- distillation or rainwater collection

- 100% recycle system
- super conservation plus dual system
- recycle plus dual system
- distillation or rainwater collection

- improved treatment, high tech aerobic, management
- elimination of discharge, 100% recycle or transport off site
- reduced pollutant load, black wastes handled seperately, only grey water recharged
- alternative soil disposal systems (mounds)

- alternative soil disposal system mound, etc.
- reduction flows, super conservation or partial recycle
- eliminate discharge, 100% recycle or transport off site
- surface water discharge
- ET systems

Figure 5: Example Site Constraints and Options for Surmounting Them

- Quality

  In some areas, such as islands or sites with contaminated groundwater there may be a plentiful non-potable water supply. Whether the contamination is minor or severe, the alternatives are to treat or to import water. If the available water supply is of sufficient quality for some purposes but not for others, it might be reasonable to install a dual water supply system with potable water going to the bathroom and kitchen sinks and secondary water piped to all other fixtures. If the non-potable water supply is only slightly contaminated, bottled water may be sufficient to supply water for drinking and cooking.

- Quantity

  Where there is a limited supply of potable quality water, the recommended options are quite different. Conservation, use of a waterless or recycling toilet and recycling greywater for non-potable uses would result in considerable reduction in water demand. A high technology system which treats all wastewater to drinking water standards may be appropriate. Augmentation of the water supply by rain water collection and solar distillation may be desirable.

- Quality and Quantity

  In this extreme situation, augmentation of the water supply through rain water collection or solar distillation along with measures to restrict use via conservation and recycling may be appropriate. In some cases, the high technology 100 % recycling systems may be one reliable, although expensive, option.

Constraints on the Disposal of Wastewater--

As the standards for installation of septic tanks and soil absorption systems become more stringent fewer undeveloped sites will qualify. The pressure for alternative on-site wastewater management techniques is expected to increase.

- Restriction of Effluent Quality

  There may be increasing restrictions on the quality of effluent discharged from on-site wastewater management systems to protect sensitive aquifers, wetlands and suface waters. In these cases more complex technologies may be required to meet water quality standards. It may be prudent in these cases to substantially reduce the pollutant load by installing a waterless or recycling toilet. Water conservation efforts will not solve this problem.

- Restrictions on Hydraulic Load

  Alternative disposal systems such as mounds or mechanical evaporators may be applicable for sites with extremely low absorption capacity such as those with clay soil or exposed bedrock. In many cases, reducing hydraulic load through water conservation and installation of water efficient fixtures may be sufficient. Only in extreme cases would 100 % recycle systems be appropriate.

Structural Constraints

A utility system is only one component in an integrated housing unit. The systems are, of necessity, all interconnected. The typical market house has evolved to accommodate conventional utility systems. The installation of an alternative utility system may require modifications to other utilities and/or the structure, placing demands on limited resources such as power, space and operator knowledge.

Space Conflicts--

Space conflicts may arise with the installation of many types of alternative utility systems, and are often the result of a need to store a resource on-site. For example, solar heating systems, whether active or passive, require that heat be collected during day light hours and stored for later use. The thermal mass must be positioned so that it can take on heat during periods of sunlight and release heat when it is needed. In active systems the storage may be located in a portion of a basement, under a foundation, or in subsurface storage tanks. Provisions must be made for the mechanical equipment (either pumps or fans) and controls. Storage facilities are also necessary for on-site electrical power geneation. Wind generators or photovoltaic systems do not necessarily produce electricity when it is needed. A bank of chemical batteries, which has been and will probably continue to be the most typical storage mechanism, requires heated utility space. There is some research into the use of fly-wheels which also require significant space for residential electrical storage.

Space requirements for the storage of solid waste prior to resource recovery are significant. Source separation of residential solid waste into bottles, aluminum, steel cans, paper and general refuse is considered the most practical route to extensive resource recovery yet it can be a burden both in in terms of space and labor. While the incorporation of storage facilities for multiple solid waste streams may be practical in large residential developments, inclusion of the necessary unheated utility space in individaul homes is unlikely.

For alternative water/wastewater systems there may be space requirements for storage tanks, treatment units and pumping equipment, control panels and supplies. Although some tanks can be placed underground, the majority of the additional equipment must be located in heated utility space.

Another example would be the amount of space required for a large volume composting toilet. Not only is there a significant floor area requirement but the space is further constrained in that it must be on a level below the toilet. It is generally preferred to locate the composting tank in a basement, a space not anticipated in most year 2000 homes. In addition, even if insulated, the tank requires some heat input and there must be a 6-12" diameter vent to the roof of the building. These requirements make the large compost toilets incompatible with slab construction or mobile homes.

Additional space required for alternative systems must either be added to the overall size of the home or subtracted from the living space.

Complexity

In a majority of situations an increase in complexity is a direct result of integrating two or more systems. This complexity often arises from the need to match outputs of one system with the demands of another. For example, consider a greywater toilet flushing system which requires a pump to provide a pressurized water supply to the toilet; a storage tank to match the production of greywater with the toilet flushing pattern; and a treatment unit to make the greywater compatible with its intended use. For each step mechanical or electrical equipment and monitoring and control systems must be installed and maintained.

Increased complexity introduces two major risks: equipment failure and operator failure. Each piece of equipment placed in a home will eventually break down; motors burn out, compressors wear out, pump impellers become pitted, etc. Such breakdowns inevitably result in service interruptions.

Perhaps more serious than the risk of mechanical or electrical failure is that of operator failure. The conventional water/wastewater system, for example, has evolved to protect the user against error. The water supply is pumped into the home under pressure and after a single use all wastewater flows by gravity into the household sewer. The conventional septic tank has sufficient volume to buffer against shock loads and there are few maintenance requirements on the user. However, if a dual water supply or a greywater recycling system is introduced, one has non-potable as well as potable water transported under pressure. There is a risk that sometime in the next ten to fifty years the piping will get confused. Washing a paint brush is not going to upset a septic tank but would present a potential risk if the wastes entered a greywater irrigation system.

The typical homeowner is not prepared to maintain sophisticated equipment. As more complex equipment is installed a service industry should develop to provide the same level of maintenance homeowners currently get on their oil burners. The high technology firms offering water recycling technology have recognized this and have mandatory service contracts for the initial few years of operation.

Health Risks

There may be increased health risks associated with the installation of alternative water and waste management technologies. While the possibility of transmitting pathogens exists in any waste management system, innovative systems which involve more user contact with waste streams may present a slightly higher risk. Waterless toilets, greywater and wastewater recycling and dual water systems, must be designed to minimize possible transmission of pathogenic organisms.

Precautionary measures can greatly reduce the risk of pathogen transfer. However, even systems which provide extensive waste treatment prior to user contact may experience an operational failure which would expose the user to partially treated or untreated wastes. Before alternative systems gain regulatory acceptance, it must be demonstrated that the potential risk of pathogen transfer is no greater than with conventional technologies.

Toxic accumulation may also present a health risk as air and water are recirculated within a residential unit. The accumulation of heavy metals and salts in the soils irrigated with treated or untreated wastewater could present a hazard, particularly when food crops are raised. Similarly, contamination of indoor air may be severe in very well insulated houses. Steps should be taken to reduce these risks.

Restricting the entry of toxic substances into the household waste streams is one simple way to reduce risk. Careful selection of the cleaning products used in the home and establishing procedures for disposing of noncompatible substances would be required as a minimum. Such restrictions, while relatively easy to define are a greater challenge to enforce, particularly with children and guests. Another option would be to implement a monitoring program to determine the levels of potentially hazardous substances in background soils and waste streams. While this approach may prove useful as a research tool, it would be cumbersome and costly for continual implementation in a residence.

SECTION 5

INTEGRATED SYSTEMS

INTRODUCTION

The range of innovative utility systems were screened to determine the most productive avenues for continued research. The focus was on systems which involve the integration of two or more of the basic utility systems: waste management, water supply, food production and on-site energy. Since electricity generated on-site is indistinguishable in its use from grid electricity, only solar heat and mechanical wind energy have been considered for on-site energy components of integrated systems.

The first step is to identify conceivable integrations of these basic utilities. Figure 6 summarizes how the outputs of each utility might be utilized as an input into another. Table 6 presents the reasons for not evaluating certain of the conceivable integrations.

Table 7 lists the integrated systems examined in this report. The inputs and outputs are designated and an evaluation of the system's contribution to the overall resource efficiency of the residence is provided.

RESOURCE POTENTIAL

The Baseline House presented in Section 2 outlines resource requirements for a residential dwelling in the year 2000. In Table 6 in that section, the anticipated inputs and outputs for the various utility systems are specified. Before evaluating the integrated systems considered during this study, it is useful to consider the maximum possible contribution that integrations can make toward overall resource efficiency.

Heat Energy

Solid waste and greywater both represent potential sources of heat energy. In section 3 it was estimated that while heat recovery from greywater with no water conservation could reduce the annual water heating load to approximately 67,000 BTU/day, extensive hot water conservation could reduce the load to about 25,000 BTU/day at a much lower capital cost. Thus, heat recovery from greywater should not be considered as a serious contributor to overall resource efficiency.

Inputs \ Outputs	Waste Management	Potable Water Supply	Food Production	On-Site Energy
Waste Management		• Source requiring treatment	• Nutrients • Wastewater irrigation • Aquaculture	• Combustion fuel • Methane • Biomass
Potable Water Supply	• Waste carriage • Carriage of chemicals used in treatment		• Irrigation • Processing (canning, cleaning, etc.)	• Low head hydro
On-Site Food Production	• Yard waste for compost • Fiber needed for operation of compost toilets			• Yard waste for methane
On-Site Energy Production	• Mechanical stirring • Heat • Pasturization • Drying • Pumping	• Distillation • Pumping • Heating • Disinfection	• Cooling • Greenhouse • Pump irrigation water • Power processing equipment (solar food dryer)	

Figure 6: Conceivable Integrations

TABLE 6: INTEGRATIONS NOT STUDIED

INTEGRATION	REASON FOR NOT EVALUATIING INTEGRATION
Use of potable water to transport wastes	Conventional practice.
Use of potable water to irrigate	Conventional practice.
Low head hydro	A very site specific method used to generate electricity on-site. None of the on-site electrical generating techniques are evaluated in detail.
Solar hot water	Well demonstrated state of the art technology
Potable water carriage of chemicals for wastewater treatment	Conventional practice.
Potable water for food processing	Conventional practice.
Food wastes as fiber for operating compost toilet	Concept utilized in commercially available compost toilet.
On-site energy for pumping water and wastewater	Commercially available technology.
Wastewater treated for potable reuse	Commercially available technology.

TABLE 7: INTEGRATED UTILITY SYSTEMS

Integrated Utility Systems	INPUTS FROM		OUTPUTS TO				DEVELOPMENT STATUS		
	Waste Management	Energy Production	Waste Management	Water Supply	Food Production	Energy Production	ommercially Available	RD & D Marginal	Research
Anaerobic digestion	x	x	x		x	x		x	
Solar assisted composting	x	x	x		x		x		
Heat Recovery from wastewater	x					x			x
Wastepaper as fuel	x		x			x	x		
Productive green-house food production	x	x	x		x	x			x
Productive greenhouse Bio mass production	x	x	x			x			x
Exterior irrigation with wastewater	x		x		x		x		
Solar distillation for drinking water		x		x			x	x	
Solar pasteurization wastewater		x	x					x	
Solar pasteurization sludges and composts		x	x						x
Solar ET wastewater		x	x					x	

Combustion of solid waste is a potential source of heat energy. Adopting a value of 1,986 BTU/Kg (4,380 BTU/lb) for energy content of residential solid waste (EPA, 1978), a high heating value for raw refuse at 25% moisture, and an estimated solid waste production at 2847 Kg/year (6,278 lb/year), the energy value of solid waste from a single-family residence is approximately 27.5 x 10^6 BTU/year. Thus even taking losses due to inefficiencies in combustion into account, the burning of solid waste could make a significant contribution to the auxiliary heating requirements of 21.3 x 10^6 BTU/year.

Methane Gas

Although small methane gas digestors have been built, none have been identified which operated on 100% residential wastes. However, later in this chapter the preliminary design of such a system is suggested. The proposed waste stream into the digester includes yard, food and paper wastes, and human excrement. Assuming optimal performance, this system might produce 719 M^3 of methane gas/year which would be equivalent to 14.4 x 10^6 BTU/year. This is approximately double the anticipated cooking fuel requirements or 60% of the auxiliary space heating requirements for the year 2000 house.

Nutrient

The nutrients of concern are phosphorus and nitrogen, the most common soil amendments. Maximum nutrient recovery would be achieved if the nutrients from yard wastes, food wastes, human excrement, and greywater could be returned to the soil. The nitrogen and phosphorus content of these waste streams and thus the maximum nutrient recovery potential is presented in Table 8. The total nitrogen content of the waste steams of 39.6 kg per year can be compared to an estimated 10 kg* of nitrogen required for a 506 m^2 (1/8 acre) lawn of the year 2000 house.

Water

The issue of recycling water versus the installation of more efficient fixtures has already been discussed in Section 4 of this report. According to Siegrist** wastewater generation for a typical household with a garbage disposal is 197 liters (52 gal.) per capita per day which for a family of four would be 787 liters (208 gal.) per day. By installing more efficient fixtures, specifically a very low flow toilet, shower flow controls, faucet aerators, and a sudsave washer, the rate is reduced to approximately 102 liters (27 gal.) per capita per day or 408 liters (108 gal.) per day for the household. The above figures account only for indoor water uses. Depending on the regional and seasonal variations, exterior water use may or may not be significant. In areas with significant year round outdoor water requirements, particularly for lawn and shrubbery irrigation, wastewater reuse should definitely be considered as a means of improving overall resource efficiency of the residential unit.

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*Victory Garden, James Crockett

**Siegrist, R.L., Waste Characteristics

TABLE 8: Annual Nitrogen & Phosphorous Production for the Base Case House

Type of Waste	Annual Waste Production (Net Wet Weight in kg.)	Annual N Production (kg.)	Annual P Production (kg.)
Yard Waste	537	12.1	----
Food Waste	486	12.0	----
Total Human Excrement	1675	12.7	1.8
Urine	1456	8.1	0.9
Feces	219	4.6	0.9
Greywater (basins, sinks, appliances) with conv. appliances	160,314	2.8	4.1*
TOTAL	163,012	39.6	5.9

References:

Other Homes and Garbage
Waste Characteristics, R. L. Siegrist, P.E.
Personal Communications, R. L. Siegrist, P.E.

INTEGRATED SYSTEMS

The following sections discuss the integrated systems listed in Table 5.

Anaerobic Digester

Application

Anaerobic digestion has been proposed as a method for on-site waste treatment. The advantage is that the process would convert the wastes into products for reuse on-site. The methane could be used to reduce dependence on fossil fuels and the sludge, which contains nitrogen, phosphorus, potassium, and trace elements, would make an excellent soil amendment. In theory, a digester could be designed so as to optimize methane generation.

Utilities and Resources Utilized

The nutrient value of paper, food and yard wastes, human excreta, and greywater contaminants is often ignored. However, with an anaerobic digester the nutrients from these wastes might be recovered. Electricity (or some other source of power) may be required for the mechanical elements of a digester, and heat must be added if optimal methane production is desired.

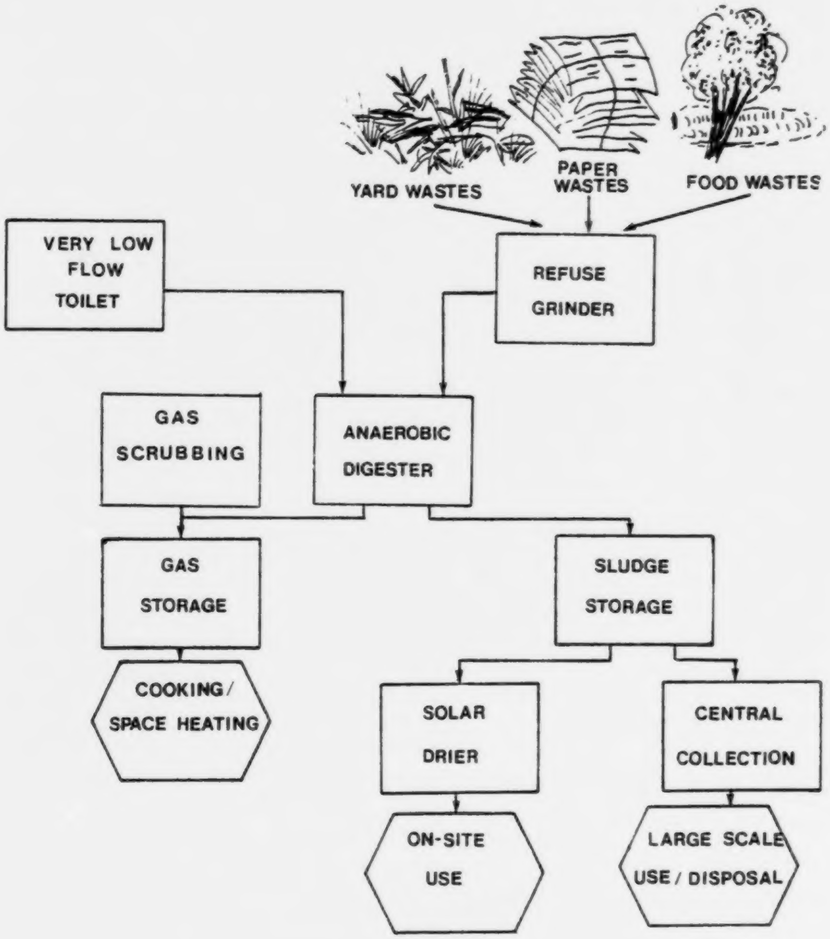
System Description

The digester tank is the primary component of the conventional anaerobic system. Raw wastes are added either periodically or continuously. If possible, the wastes are mixed -- usually by a mechanical device. Anaerobic conditions facilitate growth of bacteria which break down the wastes. A by-product of this process is Biogas -- which is composed of approximately 2/3 methane and 1/3 carbon dioxide with small additional amounts of water, nitrogen, carbon monoxide, and hydrogen sulfide. The size and complexity of a digester system are based on the user's desired capital and maintenance inputs and expected outputs. A schematic of the digester system used for this analysis is shown in Figure 7.

The design of a digester as well as the anticipated quantities of the products is dependent on the assumptions made regarding waste inputs and operating conditions. We have examined five different preliminary designs, each with a different objective. The detailed calculations for these designs are presented in Appendix C. Table 9 summarizes these designs in terms of the wastes processed, the size of the major components and the quantities of the products produced. The basic requirements for all digesters include the maintenance of the proper pH, waste volume, carbon-to-nitrogen ratio, and the avoidance of wastes which disrupt the digestion process such as citrus peels, heavy metals, ammonia, and alkali elements. Because of its low solids content, greywater may pose a problem to the digester and could probably be treated more efficiently by other means. The flow diagram in Figure 7 illustrates a system in which wastes from a very low flush toilet and refuse grinder (designed to shred food, yard, and paper wastes) are added to the

Figure 7

SCHEMATIC - RESIDENTIAL ANAEROBIC DIGESTER


YARD WASTES
PAPER WASTES
FOOD WASTES
VERY LOW FLOW TOILET
REFUSE GRINDER
GAS SCRUBBING
ANAEROBIC DIGESTER
GAS STORAGE
SLUDGE STORAGE
COOKING/ SPACE HEATING
SOLAR DRIER
CENTRAL COLLECTION
ON-SITE USE
LARGE SCALE USE / DISPOSAL

digester and the greywater system is completely separate. The diagram shows the greywater being recycled, but this is an option left to the designer.

Anticipated Performance

Methane production is optimized when the C/N ratio is between 30/1 and 35/1. As seen in Table 9 the C/N ratios of all the designs are considerably below the optimum. Thus, the actual performance of the proposed systems is questionable at best.

Biogas must be treated to remove moisture and carbon dioxide prior to use in conventional natural gas burning appliances. Scrubbing equipment used at sewage treatment plants is not currently available for residential scale applications. Also, as a precaution against leaks inside a residential structure, consideration would have to be given to adding a tracer compound which has a clearly indentifiable odor.

Methane is a very high quality fuel which is easily stored. It can be used on demand to perform tasks such as cooking which require a very high temperature. This convenience makes methane a very attractive renewable resource, particularly in very isolated areas. However, the production of a useful amount of methane by anaerobic digestion of residential wastes would require a significant commitment of resources in terms of capital, O&M, storage facilities and land for the application of sludge.

Anaerobic digestion could stabilize wastes adequately for complete recycling of toilet wastes to food chain crops. However, implementation of quality control strategies for an on-site facility is difficult. The fact that greywater would not be processed in this system would greatly reduce the risk of heavy metal contamination. Where waste disposal is difficult or where complete recycling of toilet wastes is desired, anaerobic digestion in which biogas is simply vented might be an option.

Research Status

Anaerobic digestion has not been reported using 100% residential wastes on a small scale. The small systems presently being operated have animal manures as a major input. In addition, these small-scale operations are limited to owner designed and built facilities on which there is little data. There are no commercially available units at the present time in the United States and demand for such units is limited to those homeowners willing to maintain the digester and utilize its products. There is considerable U.S. experience with the operation of anaerobic digesters on a large scale to treat sewage sludges and to process animal manures.

Recent research and design efforts have been directed toward the concept of the upflow anaerobic digester which consists of an expanded media bed on which the anaerobic organisms can grow. The objective of this approach is to provide anaerobic treatment to less concentrated solutions. Researchers are currently examining the possibility of using this technique on the residential level. However, they are still in the preliminary stages of determining the

TABLE 9: ANAEROBIC DIGESTER DESIGNS

Design	1	2	3	4	5
Objective	Treat all Noxious Wastes	Treat all Noxious Wastes-but reduce volume by use of waterless toilet	Increase Biogas production through use of Biogas in form of duckweed	Increase Biogas production by use of Biomas in form of waste paper	Treat only toilet and garbage disposal wastes to produce soil amendment
Wastes Processed	food, yard, toilet, kitchen paper	same as Design 1	Design 1 plus duckweed	Design 1 plus all household paper wastes	food & toilet
Influent Characteristics					
Total waste flow (ℓ/day)	50.4	24.8	113.8	19.65	33.68
Total solids (gm/day)	2012	2012	6992	1067	684
Total volital solids (gm/day)	1752	1752	6226	985	576
C/N ratio	9.8	9.8	14.4	19.3	4.1
Design Parameters					
SRT	20	20	20	20	20
Digester tank size (ℓ)	1008	485	2000	1570	673
tank for sludge annual storage (m^3)	36	18.25	73	57	6.1
Products					
Biogas: Volume m^3/year	321	321	1.500	719	105
Biogas: Heat Value (BTU/year)	6,387,500	6,387,500	25,000,000	14,380,000	2,098,750
Sludge: Volume (m^3/year)	18.32	9.1	41.15	28.12	3.05
Sludge: Solids (% solids)	2.6%	5.4%	4%	3.5%	1.35%
Sludge: Nitrogen content (kg/year)	35.5	35.5	90.00	35.5	23.4
Application rate for Sludge To 505 m^2 lawn (cm/year)	3.5	1.8	8.0	5.5	0.6

adaptability of the residential waste stream to the anaerobic treatment process.

Recommendations

Research is required to determine if anaerobic digestion of a typical residential waste stream is even technically feasible. Further consideration would then have to be given to the impacts of flow and compositional variations on the process before any practical application could be considered. The technology currently used to scrub and scent biogas on a commercial scale would have to be adapted to a residential scale.

Information systems would play an important role in the actual commercialization of any anaerobic waste management process whether for gas production or simply for waste stabilization. Research would be needed to determine which characteristics of the digestion process are the best indicators of its performance and sensors for those characteristics would have to be adapted for that application.

The use of anaerobic digestion would introduce considerable complexity to the residential utility system. The potential benefits are marginal relative to the time investment and risk of failure. Therefore, it is recommended that further research on residential anaerobic digesters be given a low priority.

SOLAR COMPOSTING

Application

Composting is a method of aerobically stabilizing wastes which has been used by farmers for hundreds of years. The concept of using solar collectors to provide desired heat and ventilation for composting is relatively new. The SOLTRAN composting toilet patented by David DelPorto of Ecos, Inc. is an example of this new technology.

Composting of food scraps is a commonly used method of recycling. However because it requires transporting the wastes to a compost pile as well as some management, this option is usually only acceptable to active gardeners. Here the possibility of a built-in solar assisted food composter with the convenience of a garbage disposal will be examined.

A primary concern with commercially available composting toilets is that wastes be separated from contact with uncomposted excrement for a period of time prior to use. Composted toilet wastes could be transferred to the described unit for additional treatment, thus reducing risk of pathogen survival.

Utilities and Resources Utilized

Inputs into such a composter would include food scraps, miscellaneous kitchen paper such as napkins, paper towels and biodegradable wrapping materials. It is likely that electrical power would be required to operate various components.

System Description

In the simplest design the homeowner would hand grind the refuse, turn the pile periodically, and monitor inputs and pile composition in terms of the following criteria:

- proper moisture (50-69%)
- proper C/N (30/1)
- adequate porosity of the pile
- good material mix and pile volume
- readily available carbonaceous substrate
- proper pH (7-8)
- temperature (55-65°C)
- good ventilation

A more sophisticated system would be energy intensive, but would require less owner maintenance. An electric grinder could be installed in a utility room directly over a compost chamber. The system might also include an electric fan to aid ventilation and an automatic mixing device. Solar collectors would provide the heat source necessary to maintain ideal temperature and moisture conditions. Finally, sensors might be used to monitor pile height, temperature, and possibly even composition.

Figure 8 is a schematic of a fairly complex solar composting system. Access to the pile can be through a basement area (ground level at line A) or from outside (line B) depending on house construction. Because system performance is hindered by sharp temperature drops, in colder climates, the pile should be well insulated.

Anticipated Performance

The maintenance criteria listed above are all necessary for proper performance. Neglecting even one of these points could result in noxious odors, insect breeding, or system disfunction. If properly operated such a composter should provide an alternative to the garbage disposal and result in the production of a usable by-product.

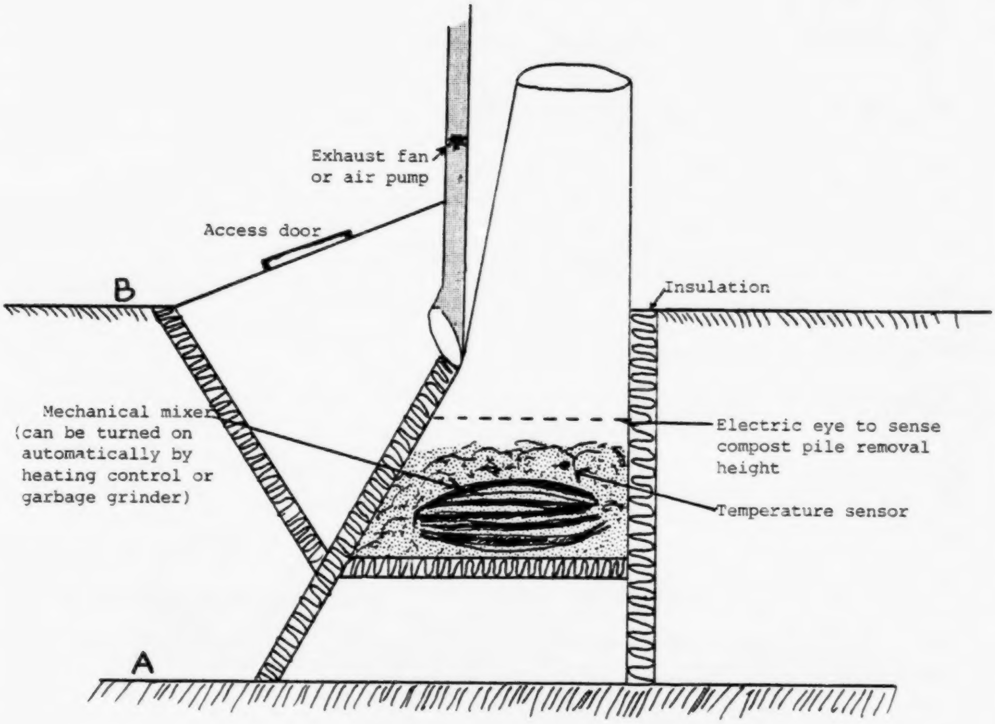
Research Status

The integration of solar and composting technologies is presently showing some potential for success. The solar element provides the heat and drying action necessary for the rapid decomposition of pile components--an important consideration for residential use, since the pile is enclosed and therefore, subject to volume constraints.

As mentioned, there has been research on the solar assisted composting of toilet wastes. However, research on applications for food waste composting

Figure 8

AUTOMATIC COMPOSTER


Exhaust fan or air pump
Access door
B
Insulation
Mechanical mixer (can be turned on automatically by heating control or garbage grinder)
Electric eye to sense compost pile removal height
Temperature sensor
A

were not identified. Automated systems are not yet available and simple mechanical systems require more labor than the average homeowner appears willing to put forth.

Recommendations

Consumer analysis investigating the potential replacement of the garbage disposal with a solar assisted automated composting unit would be useful in defining the most desirable characteristics for such a system. Research on food waste composting under controlled conditions would be valuable in determining the necessity of grinding, the optimal chamber configuration, and ventilation and heating requirements. This research can most appropriately be accomplished by private industry.

WASTEWATER HEAT RECOVERY

Application

The objective of heat recovery from household wastewater is to recycle or reuse heat that has already been purchased or gathered. Heat recovery is most attractive when the temperature of the wastewater is high or when a long dwell time in the heat exchanger can be achieved. Commercial laundries and dishwashing facilities in restaurants frequently employ a heat exchanger. Residential heat recovery units are not in common use because both flow and temperature are usually inadequate. As heat becomes more expensive, residential-scale systems may become more attractive.

Utilities and Resources Utilized

Heat is the primary resource recovered in this system. This heat could originally have been generated from a variety of sources, including solar as well as oil, gas or electricity. No other recycling or recovery is considered in this type of system.

System Description

Heat exchangers have many forms and shapes. For this type of application a simple design such as several dozen feet of finned copper tubing within an insulated storage tank, is most common. This heat exchanger should be double-walled, so that if one wall were to corrode or puncture there would be a second wall separating wastewater from the potable water. Double wall construction reduces the efficiency of the system somewhat, but is a necessary safety requirement. Estimates of the average wastewater temperature vary between just slightly higher than the temperature of water coming in from the street or well, up to that of the highest domestic hot water service temperature. Typically, the range is between 15°C and 27°C (60°F and 80°F). The temperature will also greatly depend on the water and heat conservation measures employed in the house.

Anticipated Performance

With a well-designed heat exchanger, a minimum of 2.8°C (5°F) temperature difference can be achieved between two flow streams. This means that the incoming water can be heated to a temperature 2.8°C (5°F) below the average daily wastewater temperature. The simplest use is to preheat the incoming water used for domestic hot water. The typical temperature range for a domestic water supply is between 7°C and 18°C (45°F and 65°F), and on an annual basis, is generally close to the mean annual air temperature for the region. Consequently, a 5.5 to 11°C (10 to 20°F) temperature rise might be achieved in a well-designed wastewater heat recovery system, which might provide a quarter to a third of the total heat needed to bring the incoming water up to 49°C (120°F). Thus, roughly 25-33% of the heat in a domestic hot water system could be recovered.

Research Status

Several greywater heat recovery systems have been built in experimental residences over the past ten years. The heat exchanger required is commercially available, although it is most frequently used in the solar hot water heating systems. No commercial systems were identified.

Recommendation

Recovering 25-33% of domestic hot water energy would seem to be a significant and worthwhile goal. It should be noted, however, that if extremely low flows are achieved to begin with, the amount of energy within the domestic hot water system is exceedingly small.

As shown in Section 3, the anticipated requirements for heating water in the Baseline House would be approximately 15,000 BTU/day. This is compared to the load in the typical 1980 market house of approximately 110,000 BTU/day. While heat recovery from greywater in non-water conserving homes could result in a savings of approximately 40,000 BTU/day, the savings in a low flow house would only be 5,000 BTU/day. More importantly the actual water heating requirement in the low flow house is only about 25% of that from the recovery house. Heat recovery from the wastewater is not likely to be the most cost-effective option if compared to extreme conservation. Typically, conservation is the more inexpensive option because it does not require as large a capital investment as a wastewater heat recovery system. Nonetheless, where, for some reason, conservation is not desirable, some form of heat recovery from the wastewater may be a viable option.

THE PRODUCTIVE GREENHOUSE WITH GREYWATER LEACHING BEDS

Application

Residential greenhouses have gained considerable popularity in recent years both for practical and aesthetic reasons. Greenhouses can produce space heat while providing an ideal environment for house plants, and more individuals are considering the use of greenhouses to grow edible crops as well. A solar-heated greenhouse with planting beds also designed to function as greywater leaching beds could treat the greywater, be self-sufficient for its heating needs, and a net producer of food.

A distinction should be made between a "sunspace", or a sun-room, which is designed to make a net heat contribution to a house, and a "greenhouse" which is designed to grow plants. The two have conflicting energy demands. A sunspace typically is allowed to fluctuate wildly in temperature, overheating during the day when the sun is out and dropping down to ambient temperatures at night. A greenhouse, on the other hand, must be kept at fairly stable temperatures, and never allowed to get below freezing. In cold climates, additional heat (from either an auxiliary heating system or solar heat storage) is necessary to insure that a greenhouse does not freeze during the coldest weather. Because it requires additional heat to maintain a stable temperature, a productive greenhouse generally cannot also be a net heat producer for the house.

Utilities and Resources Utilized

A productive greenhouse with greywater leaching beds would occupy part of a home's solar exposure and would require electricity for operation of controls, pumps, and mechanical equipment. A separate greywater plumbing system would be required.

System Description

A 14 m^2 (150 ft^2) greenhouse, with 9.4 m^2 (100 ft^2) of planting beds, can be cultivated to produce a majority of a family's needs for greens and vegetables. The greywater irrigation system adds the advantages of automatic watering, heat recovery, and possibly some nutrient recovery.

Clivus Multrum has three greywater greenhouses in operation. In these systems the greywater is directed to a roughing filter which removes hairs and other large particles, and also serves as a surge tank. A separate storage tank might be necessary in some cases to help regulate flow to the greenhouse. The filtered water is then pumped to the planting beds and distributed in small diameter (2.5 cm (1 inch) or less) perforated pipes buried approximately 15.2 cm (6 inches) below the soil surface.

Clivus Multrum is currently experimenting with a new subsurface irrigation pipe design which will permit more even distribution of the greywater within the bed and prevent the intrusion of roots and earthworms into the distribution lines.

The planting beds should be designed to optimize both plant growth and greywater treatment. A probable composition of the bed might be 15 to 30 cm (6 to 12 inches) of light, well-drained top soil, then 60 to 90 cm (2 to 3 ft) of graded sand and 15 cm (6 inches) of small diameter gravel. The leachate from the beds may be directed to a soil absorption system. If research indicates that sufficient treatment has been provided, the effluent might be used for surface irrigation or other secondary uses.

Placing the distribution pipes in the top soil has a number of advantages. By avoiding above-surface irrigation, greywater contact with plant leaves is minimized. Watering below the surface also reduces the overall humidity in the greenhouse, which reduces the likelihood of plant disease. Soil conditions are best maintained when irrigation water flows from near the surface downward. This flow pattern also promotes aeration of the soil, for as the water moves downward, oxygen is drawn in to the fill the vacant soil pores.

Heat recovered from greywater leaching through the planting beds could provide a significant portion of the greenhouses' heating needs. In an area like Boston, greywater from a family of four could provide 20 - 30% of a greenhouse's heating assuming:

- 64 liters (17 gals)/person-day greywater,
- 38 liters (10 gallons) is hot water at 60°C (140°F),
- inlet temperature at 12.7°C (55°F), and
- 10% of the heat is lost through use.

Under these conditions the heat content of the greywater would be 6400 BTU/person-day. Assuming a four person family has a 14 m^2 (150 ft^2) greenhouse, double-glazed, R-13 insulated walls, and back wall attached to house. Outside ambient temperature at -1°C (30°F), greenhouse at 12.7°C (55°F). The greenhouse heat loss would be approximately 87,000 BTU/day compared to 25,000 BTU/day gain from greywater. The heat provided to the soil helps to create a warm microclimate around the plants, but does not raise the general air temperature which would increase the overall heat loss. The moist soil also creates a large "thermal mass" which helps to stabilize the temperature fluctuations in the greenhouse. The heat provided by the greywater is independent of climatic conditions, and thus provides a back-up heat source on cold, sunless days.

A well designed and insulated south-facing greenhouse can generally be self-sustaining for its heating needs. In most areas of the country, more solar energy will come through a double-glazed, south-facing pane of glass than goes out as heat loss. The smaller the temperature differential that needs to be maintained between inside and outside, the more true this is. Thus, a greenhouse maintained at 10°C (50°F) is far easier to solar heat than a house which is maintained at 21°C (70°F). In very cold areas of the country more rigorous insulation measures, and some amount of auxiliary heating, may be necessary to avoid freezing temperatures in the winter.

For a solar greenhouse some form of heat storage is necessary to avoid intense overheating while the sun is shining and temperature drops when it is not. These are two common modes of thermal storage in greenhouses--water contained in tanks or tubes which passively absorbs the sun's energy and releases it later , or active storage where heat is stored by blowing warmed air through a rock bed, and then blown out again when needed. An active system has the advantage of greater control. The forced air movement also provides ventilation for the plants and greatly aids in keeping them healthy and pest-free. The fan, however, can use a significant amount of energy. The Clivus Multrum greenhouse, which has a rockbed heat storage, averaged 80 Kwh/month during the winter for fan operation.* With pumps to run the greywater system, the electrical demands of the greenhouse could easily be 1,000 Kwh per year or more.

A greenhouse greywater system has definite advantages for a residence on a small site where space for a leachfield (and outdoor garden) is a problem. Such a greenhouse could conceivably be built on top of a roof or garage, saving additional land. In densely built-up areas, such high locations generally also have the best solar exposure.

For a single-family house, a greenhouse is not likely to compete with other needs for solar exposure. A well-insulated 140 m^2 (1500 ft^2) house is likely to require only 9.3 m^2 (100 ft^2) of south window area for a reasonable passive contribution to its space heating needs. An additional 300 to 400 square feet of active collector might be added for additional solar space heating, domestic hot water and heating needs for utility systems. These areas for solar exposure can be easily accommodated on the south wall and roof of a properly oriented single-family house. Competition for solar exposure is more likely to occur in a multi-family development. While space heating needs are greatly reduced, so is south exposure. Greenhouses are likely to have to be built as a separate structure far enough away from the main building to avoid shading. They might also be incorporated into part of a separate garage structure.

Research Status

A few such greenhouses are in operation, generally modeled after the prototypes built by Clivus Multrum. Our research did not uncover any efforts to systematically test or monitor these systems. It would be important to study the quality of the leachate in order to be able to optimize the treatment capability of the planting beds. Nutrient and toxin uptake by the plants is unknown at this point. Many other smaller scale problems, mostly of a mechanical nature, remain to be worked out.

Recommendation

A productive greenhouse clearly is only applicable in situations where year-round plant production is desired, but not possible under outdoor conditions. It is predicted that a moderate size greenhouse for a family of four would require from one to two hours per week, or four to eight hours per month.** A greywater leaching bed provides an automatic watering system which can significantly reduce the amount of owner attention required by the greenhouse. It reduces the problem of drying soil during periods of overheating, which is one of the common causes of failure for residential greenhouses. The two hours per week of maintenance should be balanced against the convenience and savings of having fresh vegetables.

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*NCAT Solar Greenhouse Monitoring Program, Second Progress Report, September 1979.

**Based on time spent in family greenhouses by respondents to the NCAT Solar Greenhouse Monitoring Program, Second Progress Report, September 1979.

It is probable that a house with such a system would be sold to owners who had no interest in growing food. If greywater leaching beds provided adequate treatment even when not maintained for planting, the greenhouse structure could possibly be used as a sunspace.

Ensuring safe toxin levels, particularly in the edible parts of the plants grown, is a major limitation. Numerous toxins, both chemical and biological, such as paints, household cleaners, and bacteria from food and body wastes may enter the greywater. The most direct and safest method to control the toxin levels is to keep as many of the toxins out of the source water as possible. A second line of defense is to grow no vegetables which have edible parts in direct contact with the soil, such as root vegetables. A family who understood the importance of controlling toxins could maintain a safe level through self-policing. However, were the house to change hands, misuse of the system is a danger. This danger is significantly greater than that of a new owner growing vegetables over a traditional leach field, for in the greenhouse the plant roots have much more direct contact with greywater.

Automatic watering of a productive greenhouse can be provided through the use of a separate recirculating irrigation system, which would eliminate the risks associated with greywater recycling and provide most of the benefits. Also the use of hydroponic beds greatly increases the quantity of food which can be grown in a given space.

Because of the potential risks and limited applications, greywater irrigation of food production beds within a greenhouse may not be practical. In situations where it is desirable from a wastewater management perspective to have controlled leaching beds, ornamental plantings may be more advisable. Additional research in this area should be done by private industry in response to anticipated demand.

SOLAR DISTILLATION FOR DRINKING WATER

Application

In areas with no centralized water supply and only contaminated ground or surface water on-site, solar distillation is an option for producing a drinking and cooking water supply. Scarcity and poor quality of water is very common in areas of ample sun, making a solar technology particularly appropriate. Solar stills are basically simple, and thus comparatively inexpensive. Since approximately 1 m^2 (10 ft^2) of collector is required to produce 3.7 liters (1 gallon) of pure water per day, solar stills can be quite space intensive. Integrating solar distillation with other solar applications might lessen the space conflicts.

Utilities and Resources Utilized

A solar still requires a significant amount of the solar exposure on a typical residential unit. Electricity is needed to operate controls and mechanical equipment. A waste brine is generated which must be disposed of in an environmentally sound manner.

System Description

Traditional solar stills are of the basin or wick-type. The basin type is simply an insulated basin with a glass cover plate, possibly with several trays for liquid as shown in Figure 9. Solar energy is absorbed by the water, which then evaporates and will condense on the inside surface of the cover plate. This distilled water then flows down the sloped cover to a reservoir for collection.

Figure 10 details the wick-type solar still which uses a black synthetic webbing to trickle and trap water as it is exposed to solar radiation. Although this system has a higher efficiency than the basin type, it is likely to be unacceptable for a greywater distillation system because of possible biological contamination or growth in the webbing. For distillation of sea water, on the other hand, it would be the desired system.

A distillation system could be integrated with an active solar collector used for space heating. An "open" liquid active solar heating system, in which the water is not under pressure and can easily mix with air, has potential to also distill some of the water used to collect heat. A common example of such a system is the "trickle collector" developed by Dr. Harry Thomason. In the trickle collector, water runs down corrugated metal, painted black and covered by a layer of glazing. One reason that these sytems are not in greater use is their inefficiency, especially at low ambient air temperatures. The inefficiency is caused by the water evaporating, and then condensing on the "cold" glazing. The condensate gives off its heat to the outside rather than delivering it to the storage tank.

If the condensate could be recovered for potable water, the system would have a dual purpose, and thus much higher efficiency. Typically, 28 to 47 m^2 (300-500 ft^2) of collector is used on an average sized house. This would mean, for a climate such as Boston, production of 151 liters (40 gallons) of water per day in the summer and approximately 19 liters (5 gallons) per day in the winter on sunny days. Distilled water production would increase up to 70% in high sunshine areas such as Colorado, meeting far more than a family's daily demand for cooking and drinking water. Any collector slope greater than 45° would assure that the condensate would run down the glass rather than dripping back to the absorber plate.

Figure 9

Basin-Type Solar Still

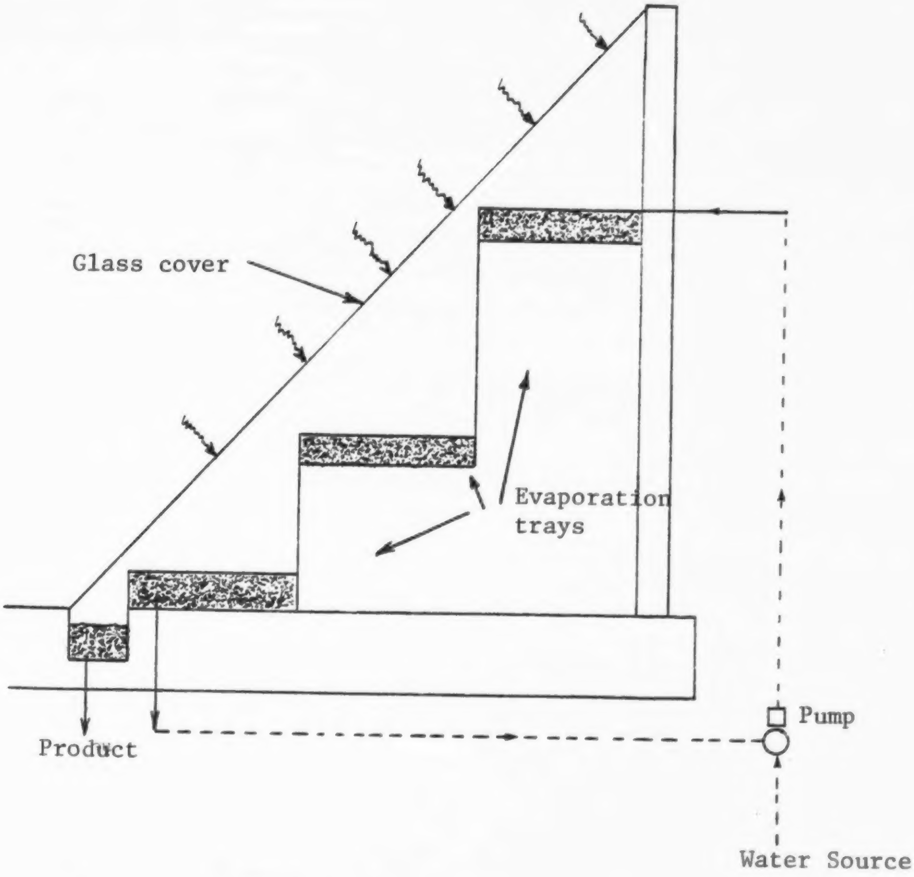
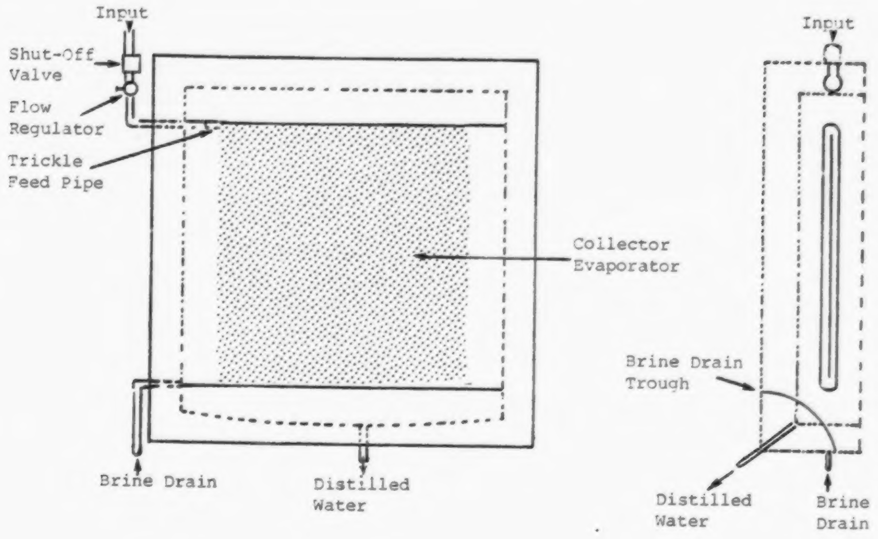

Glass cover
Evaporation trays
Pump
Product
Water Source

Figure 10

Wick-Type Solar Still


Input
Shut-Off Valve
Flow Regulator
Trickle Feed Pipe
Collector Evaporator
Brine Drain
Distilled Water
Input
Brine Drain Trough
Distilled Water
Brine Drain

Anticipated Performance

Figure 11 is a plot of experimental data for basin and wick stills of daily yield in gallons of water per square foot versus incident radiation in BTU per square foot per day. This data is from studies of two locations: Greece and Oklahoma. Other variables such as ambient temperature, wind speed, slope of cover, glazing, or incoming brine temperature are, unfortunately, not accounted for here. The lower point on the graph is for December in Greece, with the other points for May and July either in Greece or Oklahoma. Basically, performance varies between .01 and .12 gallons per square foot per day. The difference in efficiency may be due to the increased net solar radiation received by the system and lower rate of reflection from the basin.

Research Status

Solar stills are commercially available. However, the combined use of an open liquid solar heating system to also distill water has not been identified.

Recommendations

The most versatile solar water distillation option would seem to be modifying the "trickle" collector to distill non-potable well water. Because of the mechanical requirement of the trickle collector it would not be advisable to use this system to distill greywater. Two key modifications are necessary. First, the total system must be made corrosion resistant so that it can accept brackish water in the collector loop. Second, the glazing detail must be modified to channel the condensate to a suitable reservoir.

For the first problem, plastic piping and absorber plate could be used because the system operates at a relatively low temperature (below 15.5°C (60°F)) and will be in operation year round eliminating problems of high temperature stagnation in the summer.

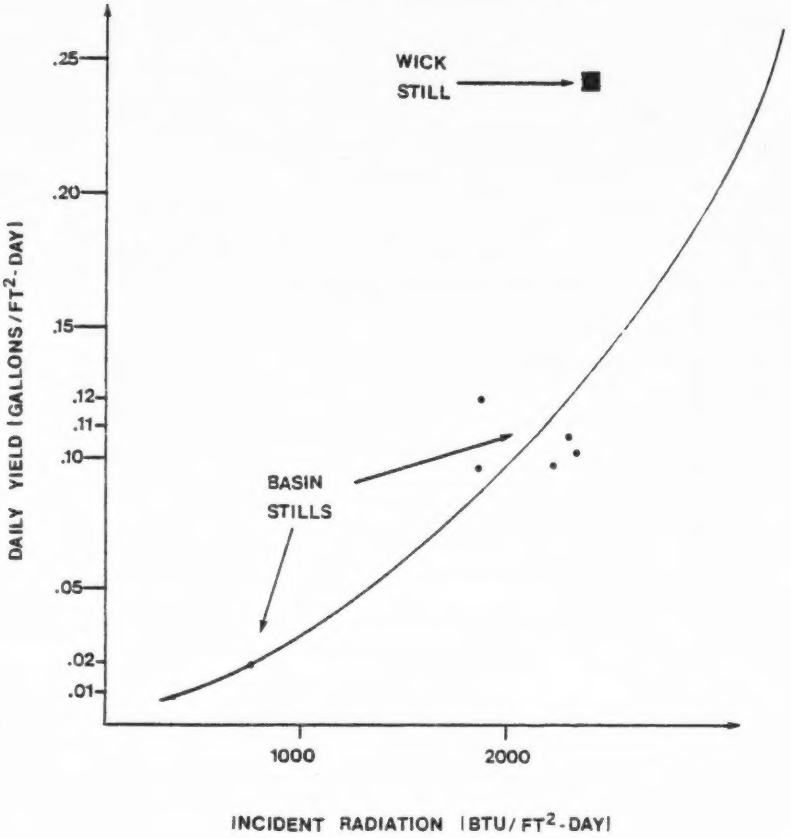
The glazing detail would require a system of ridges on the inside surface of the glazing which would channel the condensate. A specially extruded plastic glazing is one possible solution. A thin bead of silicone or plastic strip applied to a glass coverplate is also possible, although more labor intensive. The surface of the coverplate would have to be continuous from the top of the collector to the bottom to avoid creating an intermediate drip edge for the condensate. Thus, the height of the collector might be limited by the length of glazing material available.

The cost of the system would also include a distilled water storage tank and a dual water supply system for the house.

To date, there are no known examples of a trickle collector system combined with a solar distiller. However, this system has great promise simply because an existing, well-developed system would require little modification to include distillation. It should be noted that the inventor of the trickle

Figure 11

Performance of Solar Stills



collector system has devised a rain water cistern detail to be used for the north roof. Possibly the two could be integrated into one system.

SOLAR DRYING AND PASTEURIZATION OF BLACKWATER SLUDGE

Application

A solar drying unit would take the blackwater from a very low flush toilet system, and evaporate the water to make a concentrated sludge which is then pasteurized. This system might be considered if a house had no possibility for a sewer system nor septic tank with leaching field. A very low flush toilet system is required to reduce the liquid present in the sludge so that storage does not get excessive. This system would be an alternative to a composting toilet. This system would be used when a minimum of user participation is desired, adequate sun is available, and a site is available for the pasteurization tank.

Utilities and Resources Utilized

The major resource employed is the solar energy, used for pasteurization and evaporation. A small amount of electricity might be required for pumping if a holding tank were below grade and the solar unit were outside above grade. No resources are necessarily extracted from the blackwater sludge. However, the concentrated sludge might be used as a soil conditioner.

System Description

There are two main components of this system. The first is a large, vented holding tank for the black water. Venting of gases must be considered since some digestion may occur, particularly if the tank is insulated. Using a low flush toilet, approximately 9.5 liters (2.5 gallons) per day of sludge will be generated for an average house. In most climates, except for the most southern states, the system could only operate efficiently 3 to 6 months out of the year, during the warmer summer months. Consequently, a tank of approximately 1900-3785 liters (500-1,000 gallons) would be required for annual storage of the blackwater.

A major component of the system is the apparatus that is used to pasteurize and evaporate the liquid from the blackwater. A pump must be provided to transfer the concentrated blackwater mass, including any material that has settled at the bottom of the storage tank, to the solar pasterurizer and evaporation unit. Pumps which can handle this type of solid matter are costly. Also, care must be taken in the design, location, and construction of the pasteurization and evaporation unit. This unit probably should be fully automated and self-contained to avoid any fouling or need for maintenance by the homeowner.

System Performance

The performance can be roughly estimated using the evaporation rates discussed in the solar distillation section, although sludge is likely to have a higher vapor pressure than water. If the operation is limited to the three summer months, as a worst case, the following performance can be assumed. To pasteurize and evaporate 3406 liters (900 gallons) of blackwater during this three month period, approximately 9.3 m^2 (100 ft^2) of evaporation surface is required. This would require a batch-type process utilizing several batches over the summer to accomplish both pasteurization and evaporation of the contents.

Recommendation

Although it is feasible, this system has a minimal benefit compared to the amount of effort and bulk of equipment that would be required. The mechanical and construction details would have to be worked out precisely, since they would contribute heavily to the success or failure of the system. Handling of the blackwater would require either a fully automated system or could be performed by a service agent. The additional expense of the insulated tank, special pump, and outside evaporation unit, does not compare favorably to the other, simpler, types of disposal systems. Maintenance of the system and final disposal of the material would also present a problem. The solar unit would probably cost between $54 to $108 per square meter ($5 and $10 per square foot). Equally important would be the space conflicts which would arise from placing a 10.7 square meters (100 square feet) plus solar unit on a smaller lot.

No further research is recommended.

WASTEPAPER AS FUEL

Application

Each American consumes approximately 241 kg (531 lb)* of paper per year which would be the equivalent of 964 kg (2125 lb) per year for the Baseline House. Formerly, disposal and recycling were the only options available. However, new stoves have recently been developed which burn newspaper in addition to wood, cardboard, and other paper products. These stoves show improvements in efficiency and design to the point that wastepaper can fulfill substantial portions of residential heating requirements.

Utilities and Resources Utilized

The combustion of wastepaper would reduce the solid waste stream from the home substantially. Stoves designed to operate at very high combustion temperatures generally require no energy input other than a fan to help distribute the heat more evenly throughout the home.

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*Franklin Associates, Ltd. "Analysis of Environmental and Economic Impact of Waste Reduction Procedures and Policies"; September 1977.

System Description

One such paper burning stove is the COMBI-THERM.* The manufacturer claims that stove's interior baffle construction and cast iron body allows the conversion of fuel heating value to space heat with 75-80% efficiency. Since paper has a heating value of approximately 16,660 BTU/kg (7555 BTU/lb),** an extremely efficient stove (80%) burning wastepaper might contribute 12.8 x 10^6 BTU per year to the auxiliary heating requirements of the Baseline House or approximately 60%.

Efficient stove design, proper maintenance, and the rolling of newspapers into tight logs can reduce the generation of ash, thus reducing the potential adverse air qualtiy impacts of wastepaper burning. Unlike wood, paper cannot be stored outside. Moisture and sunlight will quickly decompose the paper. Thus, the paper must be stored in a dry, enclosed area. At an approximate density of 900 kg/m^3 (11.5 lb/ft^3)it would require 1.07 m^3 (129 ft^3) to store one year's worth of newspaper for the Baseline House, enabling the use of all papers during the peak heating season. If papers can be packed to a height of 1.5 meters (5 feet) at 50% efficiency, and a walk area of one meter (3.3 feet) on one side, this storage requirement translates into a shed with a floor area of approximately 2m x 2m (6ft x 7ft) which is relatively small.

Recommendation

A stove capable of burning wastepaper as well as wood currently costs approximately twice as much as a standard wood burning stove. This additional expense may well be justified by the increased efficiencey and reduced demand for wood. However, the potential health impacts of such an investment are worth further research. The potential increase in air pollution from single and multiple installations should be examined.

In more urban areas it is most advantageous for the nation to have newspapers and other wastepaper recycled into paper products. However in more rural areas where transporation costs of recycling are greater, on-site use of wastepaper as a fuel source might provide a cost-effective means of reducing both energy and waste management costs.

GREYWATER PASTEURIZATION BY SOLAR HEAT

Application

A solar pasteurizer could disinfect greywater for both pathogen and odor control. The solar pasteurization process would be attractive where both water reuse and solar hot water heating are desirable. The process is similar to the standard solar domestic hot water systems now in use and heat recovery from the pasteurization tank is possible. In this way, a cascading of energy use can be achieved.

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*The COMBI-THERM was developed in Sweden and is being distributed in this country by Clivus Multrum, Inc.

**Handbook of Solid Waste Management. Edited by David Gordon Wilson, 1977, p. 110.

Utilities and Resources Utilized

The primary resource used in this process is the greywater. Any nutrients or other chemicals in the greywater are not recovered. The primary utility is the solar heat collected by flat plate or evacuated tube collectors to heat the greywater. Since a 63°C (145°F) water temperature for at least one hour must be achieved, it is most appropriate to use active solar systems rather than passive ones. Active systems require power to operate pumps and controls and can be freeze-proofed for winter operations. The amount of power needed is extremely small since the pumps are less than 1/10 horsepower. An auxiliary or backup fuel will be required to supply heat for this process when solar energy is unavailable. Depending on the location, gas, oil, or electricity can be used. Approximately 100 to 340 m^3 (3,531 to 12,000 $feet^3$) of natural gas would be required annually for backup.

System Description

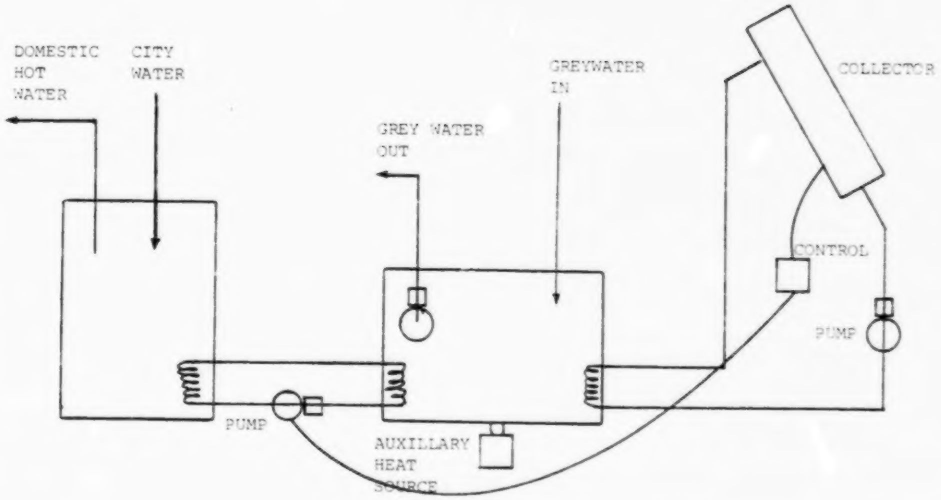
The system is very similar to the conventional active solar domestic systems now in use throughout the country. The primary exception is that the solar pre-heating tank has now been replaced by a greywater pasteurization tank. (See Figure 12.) A pasteurization tank should be sized for the peak greywater production of the particular household, constructed of corrosion resistent materials, and insulated to R-19.

Within the tank would be found a heat exchanger for the closed loop anti-freeze type solar system. The greywater would not be suitable for circulation through the flat plate collector because of potential fouling and corrosion. Typically, an anti-freeze and water solution is standard for freeze protection and corrosion control. A heat exchanger would normally be at the bottom of the greywater holding tank. The outside surface of the heat exchanger must remain relatively clean and scale-free if proper heat transfer is to take place between the collector loop and the greywater. Any build-up of debris or sludge could reduce the efficiency of the system.

The primary source of heat from the system is from the flat plate or evacuated tube collectors. The collector array size for the system would be approximately .01 to .02 m^2 of collector for one liter of greywater per day (.4 to .8 ft^2 collector per gallon of greywater per day). A pump is needed for the collector loop and another pump to distribute the pasteurized greywater. An additional heat exchanger could pass through the pasteurization tank to preheat domestic hot water. In this case, the controller would sense when the pasteurization process is complete so that heat could be removed for preheating hot water. Generally, 70-75% of this heat can be recovered.

Figure 12

SCHEMATIC DIAGRAM OF (GREYWATER)
PASTEURZATION BY SOLAR HEAT


DOMESTIC
HOT
WATER
CITY
WATER
GREYWATER
IN
COLLECTOR
GREY WATER
OUT
CONTROL
PUMP
PUMP
AUXILLARY
HEAT
SOURCE

System Performance

Liquids can be pasteurized when placed at 63°C (145°F) for one hour or 50°C (122°F) for 45 hours. An analysis was performed based on the computer program F-CHART to determine the monthly and annual performance of a solar heated system. F-CHART is primarily used to estimate performance of active solar space heating and domestic hot water systems. The proposed system is similar enough to a domestic hot water system so that the assumptions inherent in the program are believed to be valid. The following analysis is based on the use of a standard, commercially available, flat plate collector. The collector would have a single glass cover and a selective surface black chrome absorber plate and is the standard equipment presently utilized in most northern climates for domestic hot water systems. The following key input parameters were assumed:

- Daily greywater load 450 liters (120 gal)
- Output temperature 63°C (145°F)
- Input temperature 26.6°C (80°F)
- Collector area 11.2 m^2 (120 ft^2)

Using the above assumptions, the total annual heating load for pasteurization is approximately 24 x 10^6BTU per year of which the following percentages could be provided by the solar collectors:

o	Boston	52.1%
o	Miami	72.1%
o	Denver	86.1%
o	Minneapolis/St. Paul	56.4%

The remainder must be provided by an auxiliary heat source, typically gas, oil, or electricity.

It is interesting to note, that a normal domestic hot water service has a temperature setpoint of about 49°C (120°F), a temperature that can easily be achieved with a heat recovery system connected to a well-insulated pasteurization tank, which is maintained at or about 63°C (145°F). By this means, the heat energy can be cascaded from the greywater tank to the domestic hot water system.

Recommendation

Greywater pasteurization by solar heat energy appears to be a possible integration option. It involves a relatively small modification of an existing technology. This system creates no penalties to the homeowner since solar domestic hot water can be provided to the same extent that would be possible without the greywater system. The greywater pasteurization system is only incrementally more expensive than a conventional active solar domestic hot water system. An additional pump, heat exchanger, and alternate controller are the main additional costs. The greywater tank probably would be larger than a conventional domestic hot water tank because it must be sized for a typical peak load rather than an average load. Thus, adding a greywater pasteurization capacity to a solar-domestic hot water system would increase the initial cost on the order of 10 to 15%.

APPENDIX A

TECHNOLOGY EVALUATION

Introduction

The purpose of the technology evaluation was to assess currently available technologies for on-site handling of wastes and the generation, recovery and conservation of resources. The evaluation provides: 1) sufficient information so that persons with no special knowledge in a field would have a basic understanding of the capabilities and limitations of a given technology, and 2) a subjective evaluation of cost, performance and acceptability criteria. First, a set of evaluation criteria are presented in Exhibit A-1. Second, a set of charts graphically presents the evaluations for the following functions.

- On-site Power & Fuel Generation (Exhibit A-2)
- Space Conditioning (Exhibit A-3)
- Domestic Water Supply (Exhibit A-4)
- Liquid Waste (Exhibit A-5)
- Solid Waste (Exhibit A-6)
- Information (Exhibit A-7)

Finally, a description of each of the technologies is presented.

EXHIBIT A-1

EVALUATION CRITERIA

RANKING / CATEGORY	●	◒	○
Capital cost considerations, subject to --initial costs, aquisition, shipment --land costs --installation	low cost (currently competitive	medium cost (anticipated to be cost effective over the planning period or currently cost effective in special applications	high; not anticipated to be cost effective over the planning period
O&M cost considerations, subject to: --maintenance --replacement of parts --running cost --overhaul cost --disposal cost --energy recovery Establish basis such as annual cost, from which relative rating is derived	low cost (currently competitive	medium cost (anticipated to be cost effective over the planning period or currently cost effective in special applications	high; not anticipated to be cost effective over the planning period
Impacts on household water consumption	considerable conservation 5-25 gpcd	conservation 25-50 gpcd	little conservation 50-75 gpcd
Impacts on liquid waste generation: quantity	considerable reduction 5-20 gpcd	reduction 20-50 gpcd	little reduction 50-75 gpcd
Effluent Quality	body contact or better	suitable for irrigation or discharge to surface water	suitable for subsurface disposal only
Impacts on solids removed from site	considerable reduction .5 lb. pcd of dsw	reduction .5-2.0 lb. pcd of dsw	little reduction 2.0-2.5 lb. pcd
	sludge or compost removed once every 3-5 years	solid residuals removed once a year	Solid residuals removed frequently
Utilization of solid waste handled on site	complete utilization (nutrient or heat value)	partial utilization	disposal on land with no benefit
Energy consumption	0-25% of standard consumption	25%-75% standard consumption	75-100% of standard consumption
Useable heat generation	considerable generation 75-100% of household demand	moderate generation 25-75% of household demand	limited generation 5%-25% of household demand
Power generation	considerable generation 75-100%	moderate generation 25-75% of household demand	limited generation 5-25% of household demand

EXHIBIT A-1

EVALUATION CRITERIA (Cond.)

CATEGORY / RANKING	●	◒	○
Energy Conservation: Space conditioning	considerable demand reduction 75-100%	moderate demand reduction 25-75%	small demand reduction 5-25%
Power	considerable demand reduction 75-100%	moderate demand reduction 25-75%	small demand reduction 5-25%
Site considerations	not sensitive	moderately sensitive	extremely sensitive
Scale consideration	no scale restrictions	4-6 units	only large developments 6 units or more
User's acceptance subject to: noise, odor, appearance, visitors reaction	highly acceptable	acceptable with reservations	questionable
Requirements for routine owner O&M	equivalent to 5 minutes per month or less	equivalent to ½ hour per month	equivalent to 1 hour per month
Surveillance subject to: system checks	no requirement	once seasonal	once a month or more
System reliability subject to: Safety, health hazard, susceptible to shock loads, dependability on specialized personnel and availability of replacement parts	highly reliable	reasonably reliable	questionable
Special requirements on home design (to accommodate system)	no special requirements	some design considerations	major design considerations
Market availability	available commercially	custom	highly experimental
Code Acceptance	accepted by most major codes	acceptance likely	major conflicts

EXHIBIT A-2

ON-SITE POWER & FUEL GENERATION

	Capital Cost	O&M Cost	Water Consumption	Liquids Generation	Solids Generation	Usability of Solids	Energy Consumption	Heat Generation	Power Generation	Energy Conservation	Site Considerations	Scale Consideration	User Acceptance	Maintenance	Surveillance	Reliability	Design Requirement	Market Availibility	Code Acceptance	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Photovoltaics	◒	●						◒	●		○	●	●	●	◒	●	◒	◒		
Wind	◒	◒					◒	◒	◒		○	●	◒	◒		◒	○	●	○	
Methane	◒	◒		○	○	◒			○		◒	○	◒	○	○	◒	◒	◒	●	○
Biomass																				
Electrical Storage	◒	◒									◒	●	●	●	◒	◒	◒	●	●	

EXHIBIT A-3 (Cond.)

SPACE CONDITIONING

CONSERVATION AND STORAGE

	1 Capital Cost	2 O&M Cost	3 Water Consumption	4 Liquids Generation	5 Solids Generation	6 Usability of Solids	7 Energy Consumption	8 Heat Generation	9 Power Generation	10 Energy Conservation	11 Site Considerations	12 Scale Consideration	13 User Acceptance	14 Maintenance	15 Surveillance	16 Reliability	17 Design Requirement	18 Market Availibility	19 Code Acceptance	20
CONSERVATION																				
Heat recovery	◒	◒					●	○		○		○	●	●	◒	●	◒	◒	●	
Night insulation	●	●								●	●	●	◒	○	●	●	●	●	●	
Super insulation	◒	●								●	●	●	●	●	●	●	◒	●	●	
Low air exchange	●	●								●	●	●	◒	●	●	●	◒	●	●	
STORAGE																				
Salts	◒	●					●				●	●	●	●	●	◒	◒	●	●	
Low temp - rocks	●	●					●				◒	●	●	●	●	●	◒	◒	●	
Low temp - water	●	●					●				◒	●	●	●	●	●	◒	●	●	

EXHIBIT A-3 (Con'd)

SPACE CONDITIONING

COOLING

	Capital Cost	O&M Cost	Water Consumption	Liquids Generation	Solids Generation	Usability of Solids	Energy Consumption	Heat Generation	Power Generation	Energy Conservation	Site Considerations	Scale Consideration	User Acceptance	Maintenance	Surveillance	Reliability	Design Requirement	Market Availibility	Code Acceptance	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
PASSIVE SOLAR																				
Roof ponds *	◒	◒	◒				●	●			○	●	◒	◒	◒	●	○	○	●	
Solar ponds *	◒	○					●	◒		●	○	○	◒	○	○	○	○	○	◒	
Thermosiphon *	●	●					●	○			◒	●	◒	◒	●	●	◒	◒	●	
ACTIVE SOLAR																				
Solar absorption	○	◒	●				●	◒			◒	○	●	●	◒	●	◒	●	●	
OTHER																				
Evaporation	●	●	●				●				○	●	●	◒	◒	●	●	●	●	
Compression	●	◒					○	○			●	●	●	◒	◒	●	●	●	●	
Heat pump*	●	●					◒	●			◒	●	●	●	●	●	●	●	●	

*apply to both cooling and heating (see Passive solar heating)

EXHIBIT A-3 (Cond.)

SPACE CONDITIONING

HEATING (Con'd.)

OTHER	1 Capital Cost	2 O&M Cost	3 Water Consumption	4 Liquids Generation	5 Solids Generation	6 Usability of Solids	7 Energy Consumption	8 Heat Generation	9 Power Generation	10 Energy Conservation	11 Site Considerations	12 Scale Consideration	13 User Acceptance	14 Maintenance	15 Surveillance	16 Reliability	17 Design Requirement	18 Market Availibility	19 Code Acceptance	20
Electrical resistance	●	●					○	●			●	●	●	●	●	●	●	●	●	
Combustion - standard	●	●					○	●			●	●	●	●	◒	●	●	●	●	
Combustion - bio-mass	◒	◒			○	◒	○	●			◒	●	◒	○	○	◒	◒	●	◒	
Heat pump *	●	●					◒	●			◒	●	●	●	●	●	●	●	●	

EXHIBIT A-4

DOMESTIC WATER SUPPLY

	1 Capital Cost	2 O&M Cost	3 Water Consumption	4 Liquids Generation	5 Solids Generation	6 Usability of Solids	7 Energy Consumption	8 Heat Generation	9 Power Generation	10 Energy Conservation	11 Site Considerations	12 Scale Considerations	13 User Acceptance	14 Maintenance	15 Surveillance	16 Reliability	17 Design Requirement	18 Market Availibility	19 Code Acceptance	20
WATER SUPPLY																				
Wells	●	●	○				○				○	○	●	●	●	●	◒	●	●	
Solar distillation	○	◒	◒				●				○	○	◒	○	○	◒	◒	○	○	
Dual plumbing	○	◒					◒						◒	◒	○	◒	◒	●	○	
Rain water collection & cisterns																				
WATER HEATING																				
Traditional tank or tankless	●	◒					○	◒			●	●	●	●	◒	●	●	●	●	
Wood	●	●					○				○	●	◒	○	○	◒	◒	◒	◒	
Solar		●					◒	○			◒	●	●	●	●	●	●	●	●	
CONSERVATION																				
Flow reduction	●	●	◒	◒			◒			◒	●	●	◒	●	●	●	●	●	●	
Greywater heat recovery	◒	●					○	○		○	◒	●	◒	◒	◒	◒	◒	◒	◒	

EXHIBIT A-5
LIQUID WASTE

	1 Capital Cost	2 O&M Cost	3 Water Consumption	4 Liquids Generation	5 Solids Generation	6 Usability of Solids	7 Energy Consumption	8 Heat Generation	9 Power Generation	10 Energy Conservation	11 Site Considerations	12 Scale Consideration	13 User Acceptance	14 Maintenance	15 Surveillance	16 Reliability	17 Design Requirement	18 Market Availibility	19 Code Acceptance	20
TREATMENT																				
Septic Tanks	●	●		○	●	○	●				◒	●	●	●	●	◒	●	●	●	○
Aerobic Tanks	◒	◒		○	◒	○	○				◒	●	●	◒	○	◒	◒	●	●	○
Aqua culture	○	○		○	◒	●	○				○	○	◒	○	○	○	○	○	○	◒
Lagoons	●	●		○	◒	○	◒				○	○	●	◒	◒	●	◒	●	●	◒
Filters	◒	◒		○	●	○	○			○	◒	◒	◒	●	◒	◒	◒	◒	◒	◒
Disinfection	○	○	○				◒				○	○	◒	○	○	◒	◒	●	◒	◒
DISPOSAL																				
Soil absorption	●	●									○	◒	●	●	●	◒	◒	●	●	
Evapotranspiration	◒	●		◒							○	●	◒	●	◒	◒	○	◒	◒	
Solar distillation	○	○	●	○	◒		●			●	○		●	○	○	◒	○	○	○	●
Solar evaporation	○	●					●				○	●	◒	●	◒	◒	○	◒	○	

EXHIBIT A-6

SOLID WASTE

	1 Capital Cost	2 O&M Cost	3 Water Consumption	4 Liquids Generation	5 Solids Generation	6 Usability of Solids	7 Energy Consumption	8 Heat Generation	9 Power Generation	10 Energy Conservation	11 Site Considerations	12 Scale Consideration	13 User Acceptance	14 Maintenance	15 Surveillance	16 Reliability	17 Design Requirement	18 Market Availibility	19 Code Acceptance	20
Composting	●	●			◒	◒					●	●	◒	◒	◒	●	●	●	●	
Direct Combustion	○	◒			●	●		●		●	●	●	◒	○	◒	●	◒	●	●	
Grinding	●	●	○	○	◒		○				●	●	●	◒	●	●	●	●	●	
Compaction	●	●				○	●					○	●	◒	◒	◒	●	●	●	
Shredders and Chippers	○	◒				●	◒				○	●	◒	◒	○	◒	●	●	●	

EXHIBIT A-7

INFORMATION

	1 Capital Cost	2 O&M Cost	3 Water Consumption	4 Liquids Generation	5 Solids Generation	6 Usability of Solids	7 Energy Consumption	8 Heat Generation	9 Power Generation	10 Energy Conservation	11 Site Considerations	12 Scale Considerations	13 User Acceptance	14 Maintenance	15 Surveillance	16 Reliability	17 Design Requirement	18 Market Availibility	19 Code Acceptance	20
Sensors	◒	◒					●			●	●			◒	◒	◒	○	◒	◒	
Controls	●	●					◒				◒	●		◒	◒	◒	◒	●	◒	
Micro processors	●	●					●				●	●		●	◒	●	○	●	◒	

ON-SITE POWER & FUEL GENERATION

Photovoltaics

Direct conversion of sun light into electricity. Presently there are two competing technologies: thin water silicon semiconductor and cadmium sulfide. Cadmium sulfide is cheaper and less efficient (1%) than silicon (10-12%). Photovoltaics' performance can be enhanced with solar concentrators. Produces direct current; requires storage for night use. Heat recovery possible.

Wind

Wind machines are of two major types: horizontal axis and vertical axis. Most horizontal axis machines mount a propeller (similar to an airplane propeller) on a tower. The force of the wind produces mechanical spinning motion which is then transferred to a generator (or similar mechanism) where electricity is generated. Machine sizes range from less than one kw to 2.5 MW or more. Capacity factors depend on the characteristics of the machine and wind at each site but generally range from 15 to 50%.

Methane

There are no residential methane digesters commercially available in this country. Digestion is currently practical only for family farm or larger operations. The digester is a tank which holds waste and so that natural bacterial degradation occurs in an oxygen free environment (anaerobic). Human waste should be retained at least 3 months for pathogen removal. Products are bio-gas (65% methane), scum, supernatant liquid, sludge and inert solids. The proportions of these products vary with the feedstock.

Biomass

A DOE appropriate technology grant has been awarded to develop a small-scale, wood-fired steam plant, designed for electricity generation but adaptable to other direct power uses. The steam generator will be tested with several fuels, including coal, wood, and charcoal. In 1976, the Vermont Wood Energy Corporation was set up with the express purpose of developing a thermostatically controlled, automatically-fed wood chip/pellet gasifier to be used in the heating of one- and two-family homes. Since then, the group has developed a semi-automatic prototype. With the recently awarded DOE grant money, full-time work will be carried out to refine the prototype and prepare it for extensive field testing.

Electrical Storage

Batteries are currently the most common method of on-site electrical power storage. Fuel cells based on chemical reactions which release electrons, such as the conversion of hydrogen and oxygen to water, are currently experimental. Flywheels which convert electrical energy into kinetic energy could possibly be adapted for residential use. Synthetic fibers promise high strength, i.e., high kinetic energy (50,000 rpm) which might make flywheels cost effective.

SPACE CONDITIONING

Passive Solar Heating

Roof Ponds*

Water contained in plastic bags on a flat roof. Water is heated by sun and radiates heat down into house. Evaporation and radiant heat loss to night sky can be effectively used for cooling. Generally most appropriate to temperate climates with low humidity. Movable insulation is essential. Approriate only for single story structures. Very few systems in operation.

Solar Ponds*

A pond of salt water, which serves both as collector and storage. Uses reverse thermal stratification to store heat in the dense bottom salt water. Temperatures up to 190°F are possible, down to 60°F in winter. Requires a large area (1,000 ft^2 minimum). Approximately 50,000 BTU/ft^2. year productivity

Water Walls

Containerized water placed directly behind south glass so that water is directly radiated. Water walls stores more heat per volume and at a lower temperature than masonry walls and are therefore slightly more efficient. Can be translucent or painted dark color. Can be separated from living space with a thermosyphoning loop, but this lowers efficiency. Water temperatures 70° - 90°F.

Trombe Walls

Masonry walls on the south face which are glazed, integrating heat collection and storage as one unit. Heat is transferred into houses via radiation and convection from inside of wall, and/or thermocirculation vents coupling the space with the absorber surface beneath the glass. A heat wave passes slowly through wall, delivering heat to the house a few hours after peak solar radiation. 8"-16" thick. Inside surface temperature of 65° - 95°.

Sun Space

South facing room with a large amount of glazing which collects solar energy as heat. The room is allowed to swing dramatically in temperature so that it is hot on sunny days and cold at night. Excess heat can be thermosiphoned or blown into rest of house. It is an ancillary space, such as a sun porch, which is not part of the regular living space of the house.

---

*apply to both cooling and heating

Thermosiphoning Air Canals*

A flat plate air solar collector which is driven by the pressure created by the rising column of hot air. Typically, units are wall-mounted with little or no ducting and no heat storage. Has the advantage over windows that wall insulation is maintained, thus preventing night heat loss. Can be easily retrofitted and is appropriate for extreme cold climates.

Direct Gain

Using south facing windows to allow solar radiation directly into the house. Materials in the house heat up to retain some of the heat. Masonry floors or walls, or directly radiated water or salt containers store the heat and release it later. Too much window area can lead to overheating and glare problems, and actually increase the heating load in cold climates. Night insulation of windows is therefore required.

Active Solar Heating

High Temperature Concentrating Collectors

Evacuated tubes, single and double tracking Fresnel lenses. Temperatures up to 350°F. Uses include air conditioning and industrial process heat. Efficiencies vary with temperature; can go up to 60%.

Flat Plate Collectors - Air

South roof or wall mounted solar collector. Collects heat generally below 140°F. Requires heat storage system. Can be used for space heat and domestic hot water pre-heat. Can be site fabricated and integrated into building structure, or commercially purchased. No freeze protection required. Performance varies between 75,000 - 250,000 BTU/ft^2. yr. Cannot simultaneously collect and discharge from storage. Storage generally four times the volume as liquid.

Flat Plat Collectors - Liquid

South roof or wall mounted solar collector. Generally operates below 140°F. Requires a heat storage system. Can be used for space heat and domestic hot water pre-heat. Can be site-fabricated and integrated into building structure or commercially purchased. Freeze protection required in areas with more than 30 days of frost. Performance varies between 75,000 - 300,000 BTY/ft^2. yr., depending on use, load and climate.

---

*apply to both cooling and heating

Other Heating

Electric Resistance Baseboard and Radiant Panels

Standard product. 100% efficiency at site, but only 30% net efficiency of fuel utilization. Extremely low cost to install. Generally more expensive to run than oil or gas. Utilization of off-peak utility power possible to reduce operating cost, with heat storage in pressurized hot water storage.

Combustion - Standard Fuels

Typical seasonal efficiency of oil is 50% and gas is 60% of fuel energy content. This low effeciency is a result of on-off-cycling due to over sizing of systems. As heating loads are reduced, special smaller size equipment is required. Standard hot air or hot water distribution systems.

Combustion - Biomass Wood and Methane

Wood stoves, furnaces, boilers. Residential wood equipment is not automatic: requires tending. Possiblity for wood chip, burning garbage, etc. Use of alternate fuels would require the use of a high temperature furnace. Methane-typical gas burners. Change over from propane to methane standard procedure. Storage for methane requires larger volume because not generally compressed.

Electric - Heat Pumps

Heat pumps are mechanical heating and cooling devices which are able to concentrate heat. By extracting 2-3 times more heat than they consume, heat pumps have a typical efficiency (coefficent of performance) of 200% or greater. Efficiencies vary with outdoor air temperature, and frequent temperatures below 32°F make a back up system necessary. Annual cycle storage and off-peak operation are possible. Most cost effective when used to balance winter heating and summer cooling loads.

Passive Solar Cooling

Roof Ponds*

Solar Ponds*

Thermosiphon*

---

*apply to both cooling and heating (see Passive Solar Heating)

Active Solar Cooling

Solar Absorption

Solar heated hot water is used to run as absorption generator, which then provides chilled water. Absorption generator uses a chemical process which alternately boils off and absorbs the refrigerant. Requires high temperatures and therefore concentrated collectors or evacuated tubes. To be cost effective, solar should meet 80% of load.

Other Cooling

Evaporation - Swamp Coolers

Units use evaporation to cool water which is then run through a water/air heat exchanger. Requires a hot dry climate. Can cool down to 8°F of wet bulb temperature. Approximately 10% more effecient than compression cooling.

Vapor Compression

Standard air conditioning system. Window units or central systems with duct work. Requires electricity to run a compressor. Can be modified for use as a heat pump in winter.

Electric - Heat Pumps*

Conservation and Storage

Heat Recovery from Other Sources

Possibilities: outside air heat exchange, recovery from flues, recovery from greywater, heat from air conditioning coils,** heat from biological process (compost, septic). Systems generally have high capital costs for low return of heat recovered, require extra plumbing, ducting, etc.

Night Insulation

A means of reducing heat loss through windows by placing insulating material over the window at night. R-values range from R-1 for a simple plastic sheet creating a dead air space to R-15 for multiple layers of aluminized mylar. Other designs utilize foam, quilting. Airtight seals at perimeter of window are required to prevent a thermo-circulation loop past the cold windows. Saves approximately 33,000 BTU per ft^2 of window.

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*apply to both cooling and heating (see Passive Solar Heating)

**most commercially available

Super Insulation

Insulating the building envelope far in excess of current standards so that the heating load of the building can be met largely by internal gains from people and mechanical equipment. Can exacerbate the cooling loads, expecially for buildings with significant internal heat gains. Examples: greater than R-30 walls, quadruple glazing of windows, night insulation of windows, R-60 roofs, underground construction.

Low Air Exchange

Infiltration control: air lock entries, vapor barriers, super tight construction, weatherstripping, ventilation, air heat exchangers. Range from one to one tenth air changes per hour, one half the rate for current high quality construction. Three components are infiltration around windows and doors, from bathroom, kitchen and mechanical vents, flues, and door openings. Infiltration is usually the largest component in heat loss.

Storage

Salts - Phase Change Materials

Materials which can store heat through the chemical latent heat of fusion. They can store large amounts of heat in small volumes at the constant phase change temperature, typically between 70°F - 90°F. Surface area becomes a limiting factor in heat exchange. Parafins are flammable. Long-term cycling capability is in question.

Low Temperature - Rocks

3/4" to 1 1/2" diameter gravel, graded to same size, contained in an insulated air-tight container. Sizing is generally 1 cubic foot of rocks to 1 square foot of collector. 40% - 60% voids. Can store approximately 20 BTU/ft^3.

Low Temperature - Water

Water can be contained in tanks: fiberglass, steel, concrete, PVC liner, interior or underground. Requires 2 gal/ft^2 of collector. Generally not under pressure. Adaptable to heat exchanges with other systems.

DOMESTIC WATER SUPPLY

Supply

Wells

Wells are used to tap aquifers or underground streams as a water source. Generally additional treatment is not required for residential applications. On-site wells are frequently used in developing rural or suburban areas in conjunction with on-site wastewater treatment and disposal. In such cases, location and design of both well and soil absorption unit are critical. For the purposes of this project, wells frequently require power for pumping which could be supplied by wind or photovoltaics. The relatively constant annual temperature of groundwater may be utilized as a source or sink for heat pumps.

Solar Distillation

Solar evaporation with distillate recovery is a potentially attractive means of generating potable water. This technique may be particularly useful in areas where groundwater is contaminated with nitrates, some toxic chemicals, or sodium, making it undesirable for drinking water but perfectly acceptable for body contact.

The simplest solar still is a basin lined with black material enclosed by a transparent glass cover with sloping sides. Average production of such a still is 1 gal/12 ft.^{2} per day. Assuming a house were designed with kitchen sink and bathroom piped for potable water and the bath, shower, laundry, and second kitchen sink for cleaning, dishwater and outdoor faucets were piped for untreated groundwater, the consumption of potable water should be quite low, although because of demand shifts storage would be required. A 1975 estimated capital cost of $10-25 per gallon per day capacity would make solar distillation attractive only in special situations.

Dual Plumbing

Dual plumbing is required whenever both potable and non-potable water supplies are utilized. In addition to the increased cost of such systems, the risk of cross connection poses potential health hazards.

Rainwater Collection and Storage

Rainwater collection and storage is common practice for residential water supply in many parts of the world. Capital construction costs may be offset by lower pumping and water heating costs than needed for well water.

Water Heating

Traditional Tank or Tankless

Tank fired by gas or electricity. With oil, typically a tankless coil in the furnace.

Wood

Hot water coils run through wood stove with storage tank and demand type booster. Control of system is difficult. Overheating water is dangerous.

Solar

Roof-mounted flat plate collectors with storage tank and in/line demand type booster is required, usually gas or electric. Solar produces temperatures from 90°F to 160°F. Usable year round. Can be retrofitted easily.

Conservation

Flow Reduction

Methods that reduce demand for hot water such as low temperature setting, from 100°F to 160°F, washing clothes in cold water, and low flow shower and faucet heads. Low flow fixtures such as low flow toilets and very low flow showerheads can reduce overall water demand significantly.

Greywater Heat Recovery

Heat exchangers are used to recapture some heat from greywater. Special plumbing is required and large installations such as a commercial laundry are generally required to justify expense. If water is stored in basement or runs through a greenhouse, heat is recovered for space heat. Useful to prevent freezing in greenhouse. Assume 70% of heat content of water available for recovery. High capital cost, and considerable space requirements for equipment.

SOLID WASTE

Composting

Composting is used to stabilize solid organic wastes such as black wastes from waterless toilets and vegetable wastes from the kitchen and garden. On the residential level the waste is isolated for a period of time, either in a composting toilet or composting bins to allow natural decomposition. Because of their small mass, residential systems do not attain sufficiently high temperatures during decomposition to kill all pathogens. The direct reuse of residentially composed black wastes on food chain crops is not currently considered acceptable by most public health officials.

Direct Combustion

Open burning of residential trash and yard waste has been banned in most urbanizing areas under air pollution control laws. Gas fired inccinerators are often permited but are ususally not cost effective for individual homes. One air tight stove has been identified which can utilize most residential paper wastes as fuel without creasate buildup in the flue. This is achieved by preheating combustion gases to insure a very high operating temperature. Storage of paper wastes during non-heating months may present a problem with the use of this technology as a solid waste management tool.

Grinding

Food waste disposals are powered by 1/3 - 1/2 HP electric motors and require a stream of water to flush the ground wastes into the household sewer line. Disposals come in continuous or batch feed models and handle a broader range of food wastes than composting including meat scraps, dairy products, baked goods and some bones. The water use form garbage disposals is relatively small although regualtions vary widely on the use of such equipment with on-site wastewater systems.

Compaction

Commercially available residential trash compactors accept most paper and metal wastes, greatly reducing the volume. Some municipal collection equipment cannot accept trash processed in this manner. The compactors are also not recommended for glass (because it may puncture the bags) or garbage (because of high water content and odor problems). The compactors typically have 1/3 - 1/2 HP motors and operate on a very short cycle of less than one minute. Overall electrical consumption is low.

Shredders and Chippers

Wood shredders and chippers, either electric or gasoline-powered, are commercially available. These technologies help recycle nutrients from yard wastes back into the soil as leaf mulch or wood chips.

LIQUID WASTE

Treatment

Septic Tanks

The septic tank is a vessel which provides detention and anaerobic treatment of wastewater. Effluent is either transported or disposed on-site. Septic tank design and installation are carefully regulated in most states. The system is fairly simple, consumes no energy, and requires little maintenance besides periodic removal of sludge and scum.

Aerobic Tanks

In aerobic tanks, wastewater is oxygenated by a mechanical aeration pump, and degradation of the solids is accomplished by bacteria, protozoa and other aerobic microorganisms. Aerobic units require an energy source, control and mechanical equipment, and routine maintenance. This increased complexity can only be justified if the performance is significantly better. In some jurisdictions effluent from aerobic systems can be discharged to surface water if it is disinfected. However, there is considerable controversy over the field performance of these systems.

Aquaculture

Aquaculture is generally not considered a viable treatment alternative for a single-family home because of extensive climate control and O&M requirements. However, for some larger developments, the use of fixed media aquaculture system employing water hyacinths, duck weed, seaweed, etc., may be a feasible option. This alternative is still experimental.

Lagoons

Stratified facultative lagoons are commonly used for the treatment of wastewater from small communities and developments. Designed for a total retention period of 20 to 180 days in at least three consecutive cells. Effluent is generally suitable for stream discharge. Because of potential health hazards and limits on public access, this technology is limited to larger developments.

Filters

Buried, intermittent and recirculating sand filters can all be used to further treat either septic or aerobic effluent before discharge to surface water. Depending on local conditions, disinfection may be required.

Buried sand filters can be of a trench or bed design and consist of distribution tiles, a layer of filtration media and underdrains generally placed in gravel, all covered by at least six inches of top soil. Intermittent sand filters require a pumping chamber from which effluent is periodically pumped into the sand filter bed and collected in underdrains. These filters are smaller and have higher loading rates (and require more maintenance) than buried filters. In recirculating filters, the effluent in the underdrains is recycled to the pumping chamber at a recirculation rate of 4:1.

Disinfection

Disinfection methods that have proven effective against bacterial and viral pathogens for on-site application include tablet chlorination, iodine crystals, and ultraviolet irradiation.

The stacked solid tablet feeder, with a hypochlorite storage chamber and flow-through mixing provision, followed by a contact chamber is a typical chlorination system for small waste flows. Iodine, which is only slightly soluble in water, is normally used in the crystalline form. A saturator holding crystals serves as the feed device. The appropriate dosage to be added to the effluent can be controlled by pumping a designated sidestream throught the iodinator and reblending it with the main flow. An ultraviolet disinfection unit for on-site application consists of a high intensity lamp in a radiation chamber, through which a thin layer of waste water is injected for treatment. Ultraviolet light is germicidal in the wave length range of 230 to 300 nm, with optimum efficiency at 257 nm. The dosage of UV irradiation required depends on lamp intensity, wastewater trasnmissivity, exposure time and flow pattern through the unit.

Disposal

Soil Absorption

The dominant mode of effluent disposal from on-site treatment is the soil absorption system, where the effluent receives treatment in the soil as it infiltrates to the groundwater. In the simplest case, the soil absorption system involves an underground pipe network which is supposedto deliver the effluent to the soil in an even pattern. Significant variations exist, however, and must be evaluated; in addition, areas vary in their suitability for the use of SAS.

The usual criteria used for evaluating these capabilities are: soil structure and permeability; percolation rate; depth to groundwater; depth to impermeable layer; topography; and lot size.

A soil absorption system may be either a bed or trench design. The bed system consists of leach lines to distribute the effluent evenly throughout the field which is lined with clean stone and covered with soil. Trenches are similar to leaching fields except the leach lines are separated by undisturbed earth. Leaching chambers are precast concrete installed on a level bed of sand. Finally, seepage pits or dry wells are covered pits with open-joint linings which are used to disperse effluent to the surrounding soil.

Evapotranspiration

In an evapotranspiration system, the effluents are returned to the air by evaporation at the surface or transpiration through the plant systems, rather than infiltration into the groundwater. This works effectively if evaporation exceeds precipitation throughout the year. Land requirements tend to be high, and ET systems are only feasible in certain areas of the country. A mechanical evaporator has been developed.

Solar Distillation

Use of solar energy to evaporate the water portion of effluent with distillate collection and reuse.

Solar Evaporation

Ponds can be used for the evaporation of on-site domestic wastewater. In this case, annual evaporation must exceed annual precipitation. This method of disposal may be considered. May be restricted by health codes; public access restrictions are likely.

INFORMATION

Sensors

Some possibilities include: water meters; various temperature sensors; humidity; plant growth; turbidity; lighting; quantities stored (heat, septic tank level, etc.); conductivity; total carbon in wastewater; volatiles; pH. Many of these (temperature, humidity, flows, levels) are already used. Others are R&D at best. The problem is building the devices with processing and control, into systems that will work.

Controls

Current abilities for automatic control include: pumps, valves, lights, heaters, and calls for human intervention. These systems, controls, sensors and processors can be combined to control various residential processes. The biggest problems are:

1) building good sensors at reasonable cost
2) integrating

The benefits in improved system operation could be significant.

Micro Processors

There is relatively little use of micro processor - based controls either in wastewater or energy control for single-family residences. Some uses include:

1) remote read (e.g., in the kitchen) water or electric meters showing gallons or Kilowatts and $
2) the Pure Cycle (see sensors)
3) large-structure smart HVAC sensor/processor/control combinations
4) various simple level sensors and temperature sensors (thermostats) with little processing or connection to controls.

The potentials include things like automatic calls for service and diagnostics, adaptive control to optimize processed water quality and generally improve performance.

APPENDIX B

INTERVIEW REPORT

TEA: Lisa Heschong
DATE: October 25, 1979

INTERVIEWED:

Joe Sherman
Office of Energy & Building Technology and Standards
HUD
(202-755-6443)

HUD is just beginning a joint "thinking session" with NASA, on what the technology of a future house may be like. They call it their "2020 House". They are especially interested in NASA-developed technology which may be applicable to the housing industry. The project is just being formulated now. They hope to be doing substantive work in this area around this time next year.

CONTACT

Orville Lee
Head of Building Technology Group
Office of Energy & Building Technology and Standards
HUD
(202-755-0640)

Dwan McGoo
HUD
(202-755-5590)
For work on multi-family vs single-family housing surveys

Floyd Robertson
Director of Division of Technology Transfer
Office of Space-Terrestrial Applications
NASA
(202-755-2219)

INTERVIEW REPORT

TEA: Lisa Heschong
DATE: October 25, 1979

INTERVIEWED:

Don Luebs
NAHB Research
National Association of Home Builders
(301-762-4200)

He is in charge of a research project at the National Association of Home Builders to design and then build the energy efficient house of 1980. This project is very similar to the MED project (Minimum Energy Dwelling), but taking the energy issues one step further. The project is really based on the most advanced technology available today. They are currently in the design stage, and hope to build the house within the next two years.

INTERVIEW REPORT:

TEA: Lisa Heschong
DATE: October 25, 1979

INTERVIEWED:

Orville Lee
Head of Building Technology Group
Office of Energy & Building Technology and Standards
HUD
(202-755-0640)

He is in charge of pursuing HUD's link with NASA to forsee the technology of the future for building construction. HUD and NASA are just initiating a project to be called the "2020 House". It will look at what NASA technology is transferable to housing, life style trends for the next 40 years, economics, etc. They hope to have a full investigation going - a year or two, and maybe a test facility built in 1983. It's a "no-holds barred" approach to brainstorming.

CONTACT

Don Luebs
NAHB Research
(301-762-4200)
On design for the energy efficient house of the next 10 years.

Prof. W. Rybcynski

Ecology House
Brace Research Institute
McGill University
1 Stewart Park, McDonald College
St. Anne De Bellevue 89SCIO

Lee Dillard
November 20, 1979

The Ecology House is an early example of residential utilities integration and resource conservation. Although the house still exists, the project ended in 1972. Part of the focus of this project was on technology that would be appropriate in developing countries as well as in the 1st world. The house is a prototype meant for the tropical belt.

There are two water systems. The first is a rainwater collection tank that holds water to be used for showers, laundry, handwashing and hairwashing. The top of the toilet is a basin with a tap for this water. The water used is then drained into the toilet cistern where it is used for flushes. The wastes flow into a buried aerated treatment tank. Treated black water is hand pumped back to the toilet to supplement the water from the rainwater tank into a holding tank under the shower. It is then hand pumped up to a solar distillation device on the roof, and purified for drinking. Handpowered atomizers are installed on all water fixtures to reduce flows. An inline water heater, installed near the showerhead eliminates heat loss during storage.

Electrical power is generated by a windmill and the kitchen is equipped with solar cookers.

Chris Alsten & William Steward

Lee Dillard
December 12, 1979

Solar Aqua Systems, Inc.
PO Box 88
Encinitas, CA 92024
(714) 753-0649

Solar Aqua Systems (SAS) has a small demonstration facility at Cardiff, California treating a side stream from the influent to the existing conventional sewage treatment facility. This pilot project employs the "Anaerobic" and "Aerobic with plant cover" processes described below. The firm designed a municipal installation for the city of Hercules which will eventually harvest the plant cover for methane production. They are in the process of presenting a plan for the city of San Diego.

The Anaerobic AquaCell is SAS's most recently developed treatment process for low cost, reliable treatment of wastewater. It consists of two stages or cells. The first stage is an anaerobic contact process in which raw wastewater percolates upwards through a bed of biologically active sludge, inducing sedimentation, entrapment of heavy metals and grease, production of organic acids necessary for methane formation and a sludge digestion and stabilization. The second cell is a horizontal flow biofilm process, using the SAS Bio-Web System, where methane production with subsequent BOD reduction and additional suspended solids deposition takes place. Both cells are covered with a floating rubber cover for odor control, heat retention, exclusion of air (O_2), and methane gas collection. The system uses lagoon-type construction methods for reduced capital and maintenance costs. Liquid retention time is 24 to 48 hours (total for both cells) depending on local climate conditions, in order to achieve secondary treatment standards. Solids detention times range from six months to one year for Cell #1 and one to two years for Cell #2.

The original Aerobic AquaCell consists of multicell, aerated, earthen lagoons which allow inexpensive holding capacity of two to six days. The tanks contain hardy floating quatic macrophtic plants, e.g., water hyacinths and duckweeds for removal of nutrients and toxics from the wastewater components. Submerged activated Bio-Web substrates, a form of bio-film substrates, whose function is promoting an attached biological film of aerobic bacteria and protozoa. The low density, vertically suspended Bio-Webs increase the biologically active surface area to 50 times that of a conventional pond.

The design includes a greenhouse, and a solar pond cover to entrap solar heat during daytime and reduce pond heat losses at night. SAS claims that the increased temperatures result in a doubling of biological activity. Finally, the system is dual aerated with a simple diffused aeration piping system and surface aerators which also provide transfer of solar heated air.

The SAS wastewater treatment processes, including the Anaerobic AquaCell and Aerobic AquaCells with or without aquatic plant cover, can be designed as integrated systems to meet varying reuse or discharge requirements.

There are disadvantages for this system in a residential application. It demands a fixed amount of space in a situation where it may be easily accessed for maintenance. A degree of knowledge of the biological processes involved would be wise and a fairly high owner participation requirement is involved. The system really is not suited for treatment of an individual family's waste but could be considered for a multi-family application where a maintenance staff could oversee operations. In this case, flow rates would demand the size installation that is in operation at Cardiff.

The designers suggest that the anaerobic aquacell with underground wastewater disposal would be the most appropriate residential application of any of their technologies. They are using this treatment system at their office and run the wastewater out for ornamental plant irrigation.

Scotty Getty, Director and Resident

Lee Dillard
December 7, 1979

Ouroborus South
320 Westbrook Hall
77 Pleasant St., SE
University of Minnesota
Minneapolis, MN 55455

Passive Solar Sunspace

Ouroborus is an early example of residential utilities integration and resource conservation. The house was designed and built by the University of Minnesota and has been occupied since the mid-1970's.

A sunspace which is providing heat collection and storage runs half the length of the south side of the house, measuring approximately 15 ft. x 4 ft. It is a wood framed structure of single layer tempered glass with sheets of plastic tacked to the inside of the frame and has louvers for ventilation along the outside ceiling/wall joint. Heat is stored in four 50 gallon oil drums painted black and filled with water. About half of the greenhouse floor is stone and also serves as thermal mass. There is no problem with sill rot from condensation.

The sunspace is not used as a greenhouse. One attempt to cultivate seedlings failed when the space overheated. The director suggests that the space could be used as a greenhouse if the outer walls were vertical rather than at an angle. The sunspace backs up against the bathroom, a hall, and part of the kitchen. This arrangement may not be optimal.

Active Solar Space Heating

An open loop water active solar system consists of black steel panels in a sandwich configuration. Water is pumped to the roof and allowed to trickle down and heat up whereupon it is transferred to the first of three 1,000 gallon steel storage tanks. The tanks are located in the living area and are the height of the first floor and the basement. The basement portion is heavily insulated while the upper portion is encased in a wooden closet. The closet doors may be opened or closed for more heat as required.

The system has performed well although there are plans to change the collector panels from metal to an organic based (carbon) material with increased surface area.

Wind Blade Heat Generation

The 25 ft. windmill is producing 600 to 700 watts/day of electricity that is currently operating a small wall hung heater unit in the basement, and is eventually hoped to generate electrical power. This is a relatively new installation.

Ceiling Fan

A simple electric ceiling fan recirculates the warm and cool air from loft to first floor. The blades are horizontal and about 2 ft. long. This system provides a great deal of cooling in the summer.

Dry Compost Toilet

This home has a large volume composting toilet similar to the Clivus Multrum. It is made of wood and was designed for six people (5 ft. x 4 ft. x 10 ft.). It is vented on the front under the door opening. There are chutes from the toilet and the kitchen and a ventilation duct with a 1/100 hp electric motor placed near the top of the composting chamber. The toilet seat is outhouse style.

The occupants have noticed no problem with shock loads, odor or insects. Two years ago approximately 25 gallons of liquid was drained out of the system after it had been in operation over five years. Since then nothing has been done except careful feeding of the unit, especially from the kitchen. Occasionally, wind can be heard in the ventilation shaft at night. Heat is drawn out of the house to ventilate the toilet and some means of outside air ventilation are being considered.

Greywater

There is not recycling or use of the greywater at this time.

Water Conservation

Flow restrictors are in place in all of the water nozzles. Laundry is done off the premises. They are applying for money to build a solar preheat water tank. Presently the water is heated electrically.

Insulation

The house is fully bermed on the north side. The roof is sod.

Kitchen

The power saver store is equipped with a timer. A microwave oven is used since it cools faster and uses less energy to do so. The dishwasher has no heat dry cycle. The refrigerator has a more boxy design and accomodates more insulation. The dishwasher uses 15 gallons of hot water for each load.

Abbie Rockefeller

Lee Dillard and Pat Deese
November 28, 1979

Clivus Multrum, Inc.
14A Eliot St.
Cambridge, MA 02138
(617) 491-5820

CLIVUS MULTRUM (TM) COMPOSTING TOILET

Composting takes place in a fiberglass reinforced plastic tank ten feet long, four feet wide, requiring a seven foot height for installation. There are chutes for toilet and kitchen wastes and a ventilation shaft containing a small fan at the roof-line. There is a hatch on the front wall with ventilation openings below the bottom edge. This experimental unit was equipped with a spray liquid recirculation device, pumping the accumulated liquid back up to the top and releasing it in spray over the compost heap. This helps keep the mixture moist and cuts down on liquid to be removed.

Clivus Multrum is developing a toilet seat that resembles a conventional toilet and will circumvent the hesitation that results from the aesthetics of the 'black hole' out-house bench. When weight is placed on the spring loaded seat, the bottom falls out like a trap door. The seat is still being tested.

The unit accepts urine, excrement, toilet paper, Kleenex, Tampax, Kotex, paper diapers, paper towels, grease and fat, dust, vegetable and meat scraps, peelings, bones and eggshells. The composting occurs in temperatures around 90°F (32°C). Consequently pathogenic organisms are not destroyed by the heat, rather by the long pasteurization period. The tank should last the life of the house and other critical parts are estimated at ten years.

The Clivus Multrum is designed for regular use by no more than six people. Heavier use for short periods (shock loads) will have no adverse affects, however, an extended period of heavy use will result in excess accumulations of urine in the lower chamber.

CLIVUS MULTRUM (TM) GREYWATER FILTER

The filter is a conical shaped metal tank filled with rocks about one inch in diameter. There is a drain at the bottom with a small pump and a ventilation shaft on the removable top. Greywater flows in and the pump switches on to pump the filtered water out of the tank and up to a greenhouse. The owner estimates that the filter must be cleaned twice annually of hair and kitchen scraps when two people are in the house. If meticulous care has not been taken to put grease and fat in the toilet system, those, too, will accumulate in the rock filter. In this case, the manufacturer suggests removing the rocks completely and washing them in a solution or replacing them altogether.

Ms. Rockefeller says that chemical testing of the soil in the greenhouse hasn't been done. The greywater enters the greenhouse beds in conventional pvc pipes with holes drilled in them. They are buried five inches down in a three and one-half foot bed. The beds are layered from top to bottom; soil, sand, and gravel. The greywater is providing adequate moisture for plant growth and earthworms are thriving. The major concern is the possible residual accumulation in the soils and food crops. Ms. Rockefeller argues that the problem is eliminated if the water is applied under the soil rather than in a spray. There have been no adequate studies done on the affect of using untreated greywater on food crops.

George Green

Lee Dillard
December 4, 1979

The Saskatchewan Conservation House
c/o Department of Mechanical Engineering
University of Saskatchewan/Saskatoon
Saskatchewan, Canada
(306) 343-3838

This passive solar house uses 10 to 20% of the conventional amount of outside energy mainly through the reduction of heat loss. It is super insulated (R factors of up to 60), airtight, and equipped with heat recycling systems. The house employs solar shuttered windows, an old-fashioned enclosed porch, and insulated steel thermal doors. There is a wastewater heat recovery unit, a no waste ventilation unit, an airtight vapor barrier and heat exchanger. The heat exchanger is a low cost plastic model which also eliminates moisture.

Heating and hot water are supplied by an active solar system consisting of liquid solar collectors, a liquid to water heat exchanger and a water to air heat exchanger. Warmed air is then distributed through a standard forced air system.

Waste heat in greywater is reclaimed for preheating potable water. The greywater exchanger unit is one 40-liter fiberglass tank placed inside a 150-liter greywater tank insulated with 75 mm thickness of fiberglass. There is a drain valve in the bottom that is opened when a tank occasionally needs flushing out.

Michael Koblunt

Integral Urban House
Farallones Institute
1516 5th Street
Berkeley, CA
(415) 525-1150

Lee Dillard
December 13, 1979
and January 4, 1979

Farallones Institute's Integral Urban House was established in October, 1974 and opened in June 1975 while still under renovation. The Institute is a California based, non-profit research and educational organization. The House serves as a hands-on research project and site for classes and workshops. Among the ongoing projects are: waste composting, greywater recycling, solar hot water, aqua culture, small stock raising, bee keeping, a solar greenhouse and extensive gardening.

Waste System

The tank of a large capacity composting toilet is fully exposed on the ground floor. Two ducts from the main floor connect to the toilet and the kitchen. Occasionally a carbon source (sawdust, dried leaves, or weeds) is added to counterbalance the nitrogen in human fecal matter and kitchen waste. There is a faint down draft in the two openings created by a ventilating chimney equipped with a small fan. Fresh air enters the system through ducts inside the trap door.

As the material decomposes it moves slowly down the tank, taking at least two years to reach the third and last compartment. The final product is an odor free compost. Presumably, a tank of this size can accomodate the wastes of six persons for two years before the material must be removed. Since this has only been in use for a short time, compost has not been removed from it yet. There has been no problem with liquid accumulation as of yet. A separate urinal in the bathroom channels this potential excess liquid into the greywater system where it is used in the garden.

Other solid wastes, i.e., weeds, plant debris and animal manure are composted separately in airtight wooden bins approximately 1 cubic yard in volume. The fast (hot) batch method is employed to speed up processing time and avoid attracting flies and rats. The nutrient rich compost is ready for application to the garden soil in two to four weeks, depending on how often it is turned and the particle size.

Greywater Recycling System

The system channels wastewater from the bathroom shower and tub into an elevated 55 gallon steel drum. The tank permits cooling of the hot bathing water and regulation of its use in the garden. Wastewater from the kitchen sink is directed into the sewer because of its high concentration of solid matter and detergent.

The collected greywater flows from the storage to the garden through standard garden hoses. The central hose feeds several lateral hoses which distribute the water into a large garden area. Cloth bags attached to each lateral hose filter the wastewater while distributing it to a larger area. The wastewater is applied to the soil around fruit trees and vegetable crops of which only the above ground portion is eaten.

The institute is also studying ways to automatically mix the urine from the separate urinal in the bathroom with the greywater in the tank and use the combination for watering the garden. The current method calls for the urine to be in jars and mixed directly with five parts fresh water, and applied to the compost mulch between the plants.

Solar Hot Water System

Water is heated in solar panels at the ground floor level along the south side of the house. The panes cover 86 square feet and are made of 3/8 inch copper plates soldered five inches apart to copper sheets. The panes have been painted with black airplane paint to enhance heat absorbency and area protected by tempered glass to create a "greenhouse effect". The same construction features are present here with the addition of a solar chimney. The chimney is 2 ft. x 22 ft. x 6" of flat plate collector and is positioned near the other end. While the small collector is forcing warmed air into the chamber as before, the Solar Chimney is increasing the draw from the chamber. Air in the chimney is heated and begins to rise. It heats even more the longer it is in the chimney and moves faster. The draw it creates pulls the solar heated air through the compost pile so it is warmed even more effectively. In addition, a lot of liquid is being evaporated since it is in the flow path of warm air.

The solar bath house is equipped with a bread box solar water heater on the roof with a wood fired back-up heater. There is a drumwall in the shower stall itself to provide space heating. Water from the shower and sink flow into a sand filter below the structure and there are plans to use the water for landscape irrigation around the cabins. There is a bypass valve to be used in the winter which will run the greywater into a small septic tank and then to a mound. The soil isn't suitable for leach fields. Before the use of the mound system, terraces were constructed simply for leaching.

There is a two chambered vault privy where everything is done by pitchfork. Wastes are moved off of the privy into composting bins nearby. Urine is funneled separately away by means of containers hung inside the front of the opening, leading to 5 gallon tanks which are emptied in the compost bins. The vault privy has one convention bench seat stall and one squat plate.

One of the cabins is outfitted with a Clivus Multrum that has been slightly modified. The tank itself has been painted black and placed in an insulated container. The hatchdoor has been turned into a double glazed window solar collector. Vent air is pulled through this window, rather than the conventional vents, and helps to warm the pile. There is a 30 ft. stack with a turbine vent cap which seems to do little good. A regular fan is also installed in the exhaust chimney and does all of the work until the wind reaches 23 mph and the vent cap goes to work.

A conventional Toa Throne is installed in the office with no alterations and no special features.

Mr. Kroschel commented that the solar assisted privies function much better than the others but a problem of overloading persists because they are used by visitors. He believes that composting toilets are not really the way to go. With a society geared inextricably to water borne systems he feels it is much more realistic, and in the long run, effective to concentrate on low water toilets, conservation and recycling of toilet water for flushing. He is investigating some marine toilets for this purpose. The water could then be treated and used for irrigation. He considers greywater the biggest problem. Two items which he would give time are distribution systems for subsurface irrigation and up-flow filters for greywater treatment.

John H. Martin

Lisa Heschong
December 4, 1979

Sheaffer and Roland Co., Inc.
20 North Wacker Drive
Chicago, Illinois 60006
312-236-9106

John H. Martin wrote an article in Solar Energy, Volume 18, Number 6, 1976 on the plan for a six acre experimental farm outside of Chicago, Illinois, making maximum utilization of solar energy and on-site waste treatment and recycling. He was orginally working on the project through Argonne National Laboratories. I called him to ask about the current status of the project. He explained the project had been sponsored by Herbert Hadelhoffer of Rossmore Land Development, who had dropped his support when the company was going through rough financial times.

His current company, Sheaffer and Roland, is extremely active in on-site liquid waste treatment and water reuse and recovery. They are currently designing anaerobic digesters for the manure of a large dairy farm in Pennsylvania and anticipate the methane will provide fuel for half of the farm's electrical energy. They are also developing an alcohol plant for the same farmer to process his corn.

They are also developing a system for a commercial development of six million square feet near O'Hare airport which will have zero waste water discharge. Liquid wates are being treated by aeration, a sandfilter, then clorination, and then used to irrigate lawns and shrubbery.

He was aware of no individual residential liquid-waste recycling sysem, and felt in general the scale was too small to be economically attractive. He thought that fifty units or more might start to provide enough flow to justify an integrated system.

His company is interested in working on a rehabilitation job for dilapidated town houses in Chicago to both improve the energy efficiency of the units and develop on-site disposal of liquid wastes. He thought the project might be on the order of one-hundred units at urban densities.

Tom Swartz

Lisa Heschong
December 5, 1979

Environment, Kelbaugh and Lee Architects
Princeton, New Jersey
609-924-9576

Tom Swartz described the Nature Center at Milford Reservation in Pennsylvania which is currently under construction. It is a passive solar building with solar hot water and fourteen site-built composting toilets. The toilets are large capacity type built of poured concrete and heavily insulated. A lightbulb was located in the composting chamber, both to help find any inadvertantly lost objects, and to provide additional heating if necessary. The intention was to cut the compost with sand and use it as fertilizer over the 1600 acre preserve. No attempt was made to recycle grey water.

TEA has a copy of working drawings for the building.

Carol Stoner, Editor

Rodale Press
Emmaus, Pennsylvania
215-967-5171

Lisa Heschong
December 5, 1979

Carol Stoner was an author and editor for Rodale Press' book Goodbye to the Flush Toilet. I asked if Rodale was currently involved in any research or publishing projects dealing with residential waste treatment, especially integrated with other residential systems. She said Rodale was not giving any priority to residential waste treatment, and that her book had been the last of any work on the subject.

She recommended contacting other people in the area.

CONTACTS

- ECOS in Cambridge, Massachusetts, especially regarding their solar composting toilet designed for the Appalachian Mountain Club.
- Patti Nesbitt, a free-lance consultant on water quality, outside of Washington, DC, in Strassburg, Virginia (703) 465-8742. Ms. Nesbitt was a co-author on Goodbye to the Flush Toilet, and has generally been involved in liquid waste recycling, water quality and organic gardening.
- Vinton Lawrence at the Princeton Energy Group, who designed a passive solar house using Abbie Rockefeller's greenhouse greywater system. The house received a HUD Passive Solar Grant and was supposed to be monitored.
- Tom Bender at Rain Magazine.
- Pragtree Farm in Oregon which has been experimenting in aquaculture in greenhouses.

Vinton Lawrence

Lisa Heschong
December 7, 1979

Princeton Energy Group
Princeton, New Jersey
609-924-7639

Vinton Lawrence was the designer of a passive solar house in New Jersey which utilized both a Clivus toilet and greenhouse leaching bed for greywater based on Abbie Rockefeller's work. The house received a HUD passive solar design award, and is published in The First Passive Solar Home Awards compiled by the Franklin Institute for HUD.

The attached two story-greenhouse has double-wall acrylic glazing and heat storage in a water wall of 55 gallon drums. A three foot high planting bed doubles as a leaching bed for all the house's greywater. Water from sinks, shower, and washing machine drain to this system. After percolating through the greenhouse planting beds, the water goes to an exterior leaching field. The leaching field was included in the design in order to obtain state approvals.

The house's residents are careful with the system, use only Shakley cleaning products and avoid putting any chemical contaminants down the drain. Once a house guest washed out a paint brush, which was cause for concern. Lawrence suggests as improvements, a fine food strainer and grease trap should be included in the design. He reports the clients have had some problem with small food particles getting caught in the roughing filter and decomposing there.

The beds consist of five to six inches of rich compost, one and one-half to two feet of topsoil, and one foot of graduated sand and gravel. He reports that during the first percolation tests it took about one minute for water to begin flowing out of the bottom drains. He says the rate has since slowed down considerably. They seem to have more clay in the soil than they first thought, and so have been mixing in perlite to loosen up the soil. He feels the soils require the most attention of the system, both for their initial composition, and later balance. The greywater system has three vent stacks, one over the drain and one over each corner, and also has provisions to allow back flushing and direct access to the pipes.

The residents use the beds to grow botanicals and food crops, including broccoli, lettuce, and beans. He reports that they have not had problems with surges in the system from the washing machine or elsewhere.

Lawrence is very interested in having such a system monitored, so that its behavior can be better understood. He is especially interested in the net heat flow of the greenhouse system, wondering how the movement of the greywater contributes to the heat balance.

Abby Rockefeller

Residence
Contoocook, NH

Winslow Fuller
Lisa Heschong
December 1979

Abby Rockefeller gave us a tour of her summer residence at Contoocook, New Hampshire which has a working solar greenhouse/fish, greywater filter and a greenhouse watering system, and Clivus composting toilet. The most impressive system was the grey water filtering and greenhouse watering system.

This system consists of a standard Clivus greywater filter, greywater circulated pump, deep greenhouse earth beds, fish tank overflow provision, and drywell for final water disposal. Greywater is first collected and filtered through a standard Clivus greywater filter to remove hair and other solids that might clog the pump or piping. This filter is not a holding tank, although water can dwell there if little water is used. The pump (to the greenhouse) is activiated by a simple float valve which prevents the filter from overflowing. The greywater filter is filled with 3/4" gravel and is seasonally backflushed to remove entrapped material.

The greenhouse beds are approximately three feet deep and three feet wide covering three sides of the greenhouse. The greenhouse measures approximately 35' by 9' and the bed occupies about 24' so that total surface area is roughly 153 ft^2. Three plastic pipes on each side (buried about 5" below the soil surface) are used to distribute the filtered greywater evenly. The total path length is three feet to a series of drain pipes then to a drywell. (The fish pond was not receiving water at the time of our visit.) The beds are filled with earth mostly with a small bottom layer of sand (8" or so). Abby indicated that only about one foot of earth was sufficient so that the bottom two feet could be sand or gravel. Periodically, the circulator pump would start and supply the beds with water with a noticeable gurgling sound. The system was experiencing a shock load that day, being the day after a weekend house party and four loads of laundry had just been completed. A small trickle of water (maybe .5 GPM) was going to the drywell.

Nitrogen is removed if plants are being grown (and picked). Abby has a green thumb in that the greenhouse was abash with green color from the many plants growing. It was impressive to see so much health plant life without pests. Abby said that because of the mass of the beds, plants can and have gone three weeks without being watered! Also noted, was the lack of the usually high humidity of greenhouses. Since watering is "automatic" and subterranean, the air has a lower relative humnidity. This system also offers added safety in that the root systems tend not to take up micro-organisms.

At the time of our visit, the outside ambient temperature was in the high 30's, while the greenhouse air temperature was 58°F. The most exciting aspect (and obvious) is that this is an excellent and appropriate method to recover greywater "waste" heat. In fact, the soil temperature was 68°F some 8" under the surface. For a low flow system, this is probably the only way to recover greywater heat.

All in all, this was a very nice integrated system that requires user knowledge and participation. It was a nice way of handling the relatively large quantities of greywater produced by a typical residence. Toxic chemicals and wastes must not be introduced to the system which does involve an attitude change for most people who presently use modern cleaning fluids and materials.

Leonard Abbatiello

Oak Ridge National Laboratory
Oak Ridge, Tennessee
615-574-2011

Doug Funkhouser
January 7, 1980

The ACES program was a proof-of-concept experiement involving a control house and an ACES house in Knoxville. A solar house was peripherally involved in the program; however, it was operated by the University of Tennessee and TVA primarily as a demonstration, rather than research, unit.

The conclusion from the program to date is that ACES competes with solar in the winter, and is far more energy-conserving in the summer, with slightly lower initial capital cost. On a life-cycle cost basis, ACES is far and away preferable.

The project has also concluded that, based on current and projected developments, the ACES approach is more cost-effective than conventional heat-pump technology.* ACES is better than conventional heat pumps in terms of energy conservation by a factor of three, and more expensive by a factor of three, but slightly more favorable on a life cycle basis. Typical payback periods are 9 to 12 years. Cost comparisons have been restrained to ACES vs. other systems which tie into an electric grid. Gas, for example, is far less expensive than any ACES concept. Abbatiello concludes that, at electricity costs above 4¢/kWh, the advantages of storage systems are strong; thus, given rising costs of electric power, ACES is beginning to make sense.

Oak Ridge has not yet studied the consumer acceptance of the ACES concept. There are problems with marketability, including significant capital costs, large space requirements, the reluctance of financial institutions, etc. ORNL is thinking in terms of eight to ten years for initial market penetration, twenty-five years plus for widespread adoption.

ACES is complex--it must be sized properly and integrated with the facility. ORNL is finishing a design manual for contractors, manufacturers, suppliers, etc. Soon they may release a number of RFPs to capable HVAC organizations to manufacture 30 ACES systems for demonstration/initial production. They will go to selected areas and selected builders under a DOE cost-sharing arrangement.

The ACES concept includes "minimum ACES" and "full ACES". Minimum ACES incorporates a storage bin designed to accommodate either the first two weeks heating load or cooling load, whichever is less. Minimum ACES is considered suitable for retrofit.

The May 1979 brochure we have is slanted to icemaker heat pump ACES, whereas ORNL is now more interested in a coil-in-bin system. Also, costs are grossly under-estimated. Therefore, a number of more recent technical reports are being sent.

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*This reflects primarily air source heat pump data.

Gus Rocco

Doug Funkhouser
January 7, 1980

Coral Ridge Properties
Coral Springs, Florida
307-752-1100

referred by Cindy Metcalfe
Westinghouse Electric Corporation
412-255-5666

Electra III was the third in a series of homes built at Coral Ridge to attract people to the area to buy properties and homes. Electra II was actually a highly energy-inefficient home. Electra III, which I discussed with Rocco, is no longer owned by Westinghouse, and is now a private residence. As a demonstration home, it attracted 5-10,000 visitors a week, so it could not be monitored for energy loads.

The house, built in 1976, incorporates four foot overhangs, thermopane glass, insulation, hot air vents in the roof, a solar hot-water heater and a solar-heated pool, collection of waste heat from the refrigerator and a southern orientation, all of which features are marketed now, but some of which in 1976 were relatively new, hence the public exhibit of the home.

They have sold 600 houses in Southeast Florida, but rarely will the builders incorporate most of these features, because they do not want to add to the cost of the house. However, one feature commonly used in Florida is a roof vent either driven by a wind-turbine or a thermostat. Two turbine vents @$30-50 each are typically installed or one thermostat vent @$100-150.

No work was done with the water or wastewater streams in the house.

Stuart Liederman

Doug Funkhouser
January 7, 1980

New Life Farm
Drury, Missouri
417-261-2553; 417-261-2204

New Life Farm is a non-profit research and educational group. Their research is principally in the areas of sewage reduction and methane production from wastes. Their interest in the former grew out of the collapse of a sewage lagoon in the Ozarks about 1 1/2 years ago. The group provides information packets on sewage reduction and water conservation, and "pre-engineering counseling", in addition to carrying out their demonstration projects.

The Farm utilizes a large volume composting toilet, a well as a greywater filtration system. Every effort is made to use all waste as much as possible. Fresh water is brought by pump from a spring to the house where it is pumped through either a furnace or a solar hot water system then through radiators. Currently, the wastewater is filtered, and discharged to a drainage field which is a potential growing area. There are heat vents into the composting toilet from the heating system.

Steve Strong

Doug Funkhouser
January 4, 1980

Solar Design Associates
Canton, MA
(617) 828-7115

Solar Design Associates are architects and engineers with a technical background interested only in renewables and solar. They are currently designing a nine-story residential/commercial complex utilizing annual cycle principles. There is a one-million gallon water tank for thermal storage only. There are solar collectors collecting energy from May to about Thanksgiving, all of which is stored. The air conditioning load during this period is reduced by a number of architectural measures. The heat stored during the summer will be sufficient to carry the unit through the winter, including the provision of hot water. If the stored energy is insufficient for the entire heating season, heat pumps will extract from the storage available heat, reducing the temperature of the water from 120 degrees F to 40 degrees F.

This annual cycle application has not been used bythe firm on smaller houses. They have made no effort to work with the waste stream, other than installing a Clivus in a few homes. Strong states that Massachusetts is "neanderthal" in their approach to sanitary wastes, which is why the firm has not gotten involved in this area.

Roger Parrot

Putney School
Putney, Vermont
(802) 387-5566 or 387-4259

Doug Funkhouser
January 4, 1980

Rambux Singh of India has been trying to interest the Putney School in the installation of a methane digester. Singh has worked with these in India, where they typically process human excrement and the manure of one or two cows.

The project has not reached the detailed design stage, and the school does not have the required funding. The proposed digester would produce the equivalent of 16 gallons of oil per day (about 2000 cu. ft.) which would be used to heat the dairy house and the dairy manager's apartment, or be used in a tractor converted for the purpose. The heavily insulated digester is budgeted at $40,000-60,000, and will require some original design. A simple seven-year payback is projected.

The school has done no other work recycling wastes or wastewater.

Rick Madsen

Doug Funkhouser
January 4, 1980

Microphor, Inc.
PO Box 490
Willits, CA 95490
(707) 459-5563

Boston area reprsentative:

Foults Associates
Revere, MA
(617) 284-2700

Microphor distributes a low-flush toilet that utilizes two quarts of water. Instead of water, the unit uses compressed air (12-gallon air tank, 1/2 hp motor, which needs not be activated for every flush) to break up the solids and flush the waste, while the water is used only to wash the bowls. Madsen reiterated that these toilets can be used with any sewage system and that they do not cause clogging of septic lines or any other similar problems. The homeowner or operator is required to check the air line for waste buildup, and it is essential that the units be installed with the correct air and water pressure. The only technical problems have involved incorrect installation.

There have been problems convincing prospective customers that two quarts is sufficient for the flush. In addition, the units list at $410 and retail at $325 which far exceeds conventional toilet costs. The fact that the unit is available only in white also impedes sales.

The units are approved for most states and are generally available throughout the country. The first applications were at remote sites, but there have been some recent sales to private residences. No homebuilder/contractor uses these units on a regular basis. Retrofit is apparently not difficult.

E.C. Hise

Doug Funkhouser
January 4, 1980

Oak Ridge National Laboratory
Oak Ridge, TN
(615) 576-5454

Hise was involved with the Annual Cycle Energy System project (ACES). ORNL constructed three demonstration homes in Knoxville, all with the same orientations and thermal envelopes. These three houses were ACES, conventional, and solar, respectively. Local packages were put in the houses to simulate occupancy, and remote sensing was utilized.

After three years of monitoring, Hise was willing to conclude that there are no serious technical feasibility problems associated with ACES. As an example, a number of manufacturers now offer icemaker heat pumps, which are a key component of the systems. The capital cost of the ice storage bin is the major obstacle to market aceptance. A number of individuals have done payback calculations. Most -- depending on the assumptions about electricity costs used -- show a reasonably short payback period. However, he would not be more specific about this.

We have a detailed brochure describing the system; demonstration and data reports are also available if required.

Contact: Mr. L. Abbatiello, Oak Ridge National Laboratories (615) 574-2011.

David Delporto

Doug Funkhouser
January 3, 1980

ECOS
21 Imrie Rd.
Brighton, MA
(617) 782-0002

Ecos distributes a number of types of composting toilets. Delporto is a member of the New Alchemists interested in shelter design. This group is constructing the integrated shelter (the Ark), for which Delporto is designing the wastewater treatment component.

Ecos has just received a patent for a system which integrates solar heating and a composting toilet. Prototypes are in use at several AMC sites; at Southbridge; Belmont, NH; Bloomfied, CT (4H Club); and a contract is being completed with the Massachusetts Department of Environmentaal Resources.

The system can be designed as a function of expected demands -- current ones are as few as 30 uses per day, and as many as 300 per day. Active or passive solar principles may be used, though philosophically Delporto prefers passive. Heat is stored in a thermal mass (rocks). The composting tank is metal coated with epoxy to increase direct gain from the thermal mass; indirect gain is facilitated by a thermosiphon. The atmosphere is aerobic; the temperature is 90- degrees. The tank is bifurcated to allow for the evaporation of liquids. Active mixing is not anticipated, because air is forced through the upper and lower parts of the chamber. Composting time can be as short as seven days, but the usual period is six months to 1 1/2 years.

His early customers for composting toilets were ecologically and philosophically motivated. In order to develop an infrastructure of contractors and builders incorporating solar compost toilets into shelter design, an economic incentive is required. One possible incentive: substitution of his toilets for septic tanks will allow for the development of land otherwise used as leach field. Two developers he is aware of are using composting toilets on a large-scale; a condominium development in Attitash and a 140-unit development in Sturbridge. These units can be designed directly into the foundation so that concrete could be poured to form the composting chamber.

Delporto feels that current composting toilets are needlessly expensive, given the simplicity of the concept and the biological process. The maintenance required of the system is not a critical impediment to market acceptance. Although a certain amount of care is required, it is not more difficult than that required of a conventional oil-burning furnace (his example).

Delporto is designing a solar composting scheme for a municipal-scale operation. The compost could be used for agriculture.

He is also investigating a low-flush system involving a compost tank; the liquids are drained and the solids treated using compost principles.

SOLTRAN (TM) Solar Assisted Compost Toilet

Soltran differs from most composting toilets in that a solar glazing is placed at a 35 degree angle on the back wall of the structure. The heat aids the compost process and, in the latest design, evaporates the liquid that accumulates in the bottom of the tank. It also increases the ventilation by means of convectional air movement.

The only installations of this technology are in recreational situations in New England, although one project is planned for Holderness School in Vermont.

Mr. Delporto has plans for a home using this system but admits that it isn't viable for retrofit homes. Maintenance required on the system is virtually nonexistent.

Patti Nesbitt

Strasburg, Virginia
(703) 465-8742

Doug Funkhouser
January 3, 1980

Patti has done a lot of work with greywater recycling for either heat recovery or for nutrients. Her general feeling is that neither has as much potential in decentralized or on-site applications as originally thought.

She mentioned a couple of ideas:

- Heat recovery from greywater could be used to heat a waterwall. This would require a separate loop through the wall. The recovered heat would essentially preheat the waterwall. There might be corrosion problems.

- Use wastewater in solar ponds in a greenhouse for fish production. However, wastewater aquaculture is highly technical, and requires a great deal of management. Domestic wastewater is highly variable. A large-scale operation is far more feasible than the decentralized approach -- with the possible exception of cluster housing.

Her analysis of heat recovery from domestic wastewater suggests that it is not cost-effective to recover the limited quantities available.

Patti is a consultant to EPA within the Construction Grants Program, Innovative and Alternative Technologies Branch. She deals with communities of 3500 people or less to implement new on-site waste management technologies. The major problem with these systems is the management/maintenance required; which is why centralized systems have developed.

Patti would be willing to review our conceptual systems or offer other helpful comments to this project.

Pragtree Farm

Doug Funkhouser
January 3, 1980

Rt. 2, Box 190A
Arlington, Washington 98223
(206) 435-4648

Pragtree Farm is an aquaculture/alternative technology group primarily interested in growing vegetables. They publish a magazine in the field.

They used a sunken 20,000 gallon tank on the north wall of a free-standing greenhouse to culture algae for an herbivorous North African fish. Because one tank was not elevated, a focusing parabola was used to produce sufficient heat for the tank. The fish were harvested in September; winter operation would have required an auxiliary energy source.

The operation was developed by Ecotope of Seattle under a USDA grant. It was intended to be neighborhood-scale. Ecotope, which also is interested in methane production from farm wastes, has the final report on the Pragtree project.

Tom Bender

Doug Funkhouser
January 3, 1980

38755 Reed Road
Nehalem, OR 97131
(503) 368-6294

Bender was formerly with Rain Magazine. He is currently experimenting with a greywater filtering system, which uses a gravel filter and a glass filter for major solids. Bender proposed surface applications of the greywater to trees. However, the Oregon Division of Environmental Quality, which is monitoring the project, has not established criteria for such an application. The effluent has been tested a number of times; once it showed coliform, although no fecal matter had been introduced.

In general, Bender feels EPA and state specifications concerning greywater are unrealistic. Bender also stated that there is insufficient heat in greywater to bother with heat recovery, although he knows of attempts to preheat incoming cold water with greywater.

Bender's home also incorporates a number of flow-reduction approaches (e.g., foot valves on sinks), insulating shutters, solar collectors for the hot water system and a 55-gallon drum 'toilet'.

Bender recommends a recent 8-volume World Bank study on sewage systems. This study was a world-wide review of waste and water supply technologies, including technological, health and economic aspects. The study showed a logical system for evolving from one waste technology to another. The study concluded the largest cost of a sewage toilet system is the increased cost of needed water supply and water treatment.

Bender stated that alternatives to conventional sewage systems are necessary; compost toilets are a good first step, but ultimately they are too fussy. New types of ventilated pit privies would work well in some areas. The ideal approach is a combination water use reduction (2-quart toilet), holding tanks, and either a pumping system or a small-bore sewer. Market acceptance will require a more comprehensive and knowledgeable analysis of the health hazards (e.g., from chlorination) and costs of current sewage approaches, combined with more public input to the planning process.

Virginia Bulger

Amity Foundation
PO Box 7066
Eugene, Oregon 97401
(503) 484-7171

Doug Funkhouser
January 3, 1980

Amity Foundation had plans for an integrated house -- these plans have been postponed. They operate, under a DOE grant, a free-standing solar greenhouse with insulating panels for aquaculture, consisting of two tanks of 1700 gallons. The solar collection is passive. Recently they removed one of the tanks to install two hydroponic and one soil vegetable gardens.

The greenhouse is energy self-sufficient in all seasons. A Savonious windmill is used to aerate the water for the fish, which are carp, catfish, oscars and a North African fish. The fish are currently given away at frequent fish harvests at which the Foundation educates interested parties.

A trickling-filter system is used to clean the tank water, which then goes outside (in the summer) to a garden. This is currently gravity-flow; however, if the water is to be used for the inside soil garden, some changes will be required.

A detached house near the greenhouse had a compost toilet and greywater recycling system and was to be the core of the integrated house, but Foundation internal problems had precluded this.

The greenhouse is larger than one that would be used by a private residence, yet it is probably the minimum cost-effective size. It would be attractive at the community or commercial level. The amount of time required for care and maintenance is 'significant'. Contact: Bill Head (503) 726-5755, Research Director of the Aquaculture Project.

Cornie Corneilus

Doug Funkhouser
January 3, 1980

Pure Cycle
1668 Walter Court
Boulder, Colorado 80306
(303) 449-6530

Pure Cycle markets a closed-water recycling system for all domestic wastewater, including blackwater. Potable water is produced. Colorado, Wyoming and Texas have given approval to the system.

The 1500-gallon system is intended to meet all sewage and water supply needs of an average private residence, including parties and overnight/weekend guests. The System, which processes 8/10 gallons per minute, costs $9400 installed, and is not cost-effective for retrofit purposes.

The potential market is boomtowns and extremely rural areas or any area where there is a moratorium on sewer or water taps. Otherwise, contractors building homes within a reasonable distance of interceptors will find it cheaper to extend sewer lines.

Each unit is closely controlled by a microprocessor which receives data from a number of sensors at various stages. This microprocessor automatically calls in to a Service Center with data from the unit. These calls are scheduled on a regular basis, i.e., there is a standard maintenance schedule and the unit tests itself. The units are modular to facilitate replacement. If a sensor detects a malfunction, the unit is shut down and the service center called. The maintenance contract is $33/month for parts, labor and travel for the first three years -- after that the homeowner may make other arrangements for maintenance.

The company will not license other installers of their units, preferring to maintain close control. They will open a service center in any area where the expected demand is 100 units.

The process has five stages. Briefly:

- digestion, both aerobic and anaerobic
- ultrafiltration (particulate removal)
- organic adsorption (the bed material is patented)
- demineralization (ion exchange)
- sterilization with ultraviolet light.

Don Lakey
Marshall Space Flight Center
Technology Utilization Office
(205) 453-2121

This call was to gain general information about NASA's research in areas which might be useful in residential housing. Mr. Lakey recommended that we contact three other NASA offices for information related to our research.

- Ames Research Center, Moffitt Field

  Charles Kaubokawa, (415) 965-5554
  Currently designing a new NASA tech house

- Original Tech House, Langley Field

  John Samosa, (804) 827-3281

- National Space Laboratories

  B.C. Wolverton, (601) 494-2211
  Designer of a residential sized fuel gas digester which has been tested.

Tom Schultz

Irrigation Association
(301) 871-1200

Pat Deese
June 1980

This preliminary contact was made to identify possible alternatives to the traditional SAS system for the disposal of residential wastewater.

Drip Irrigation:

Most drip irrigation methods are difficult to operate, taking a considerable amount of effort to see that the lines do not clog with slime. Two methods of relieving the clogging are the periodical dose with a chlorine solution or to back flush with high pressure water. In many cases this action is required too frequently to make them attractive for the homeowner.

Root System Irrigation:

Root system irrigation has been developed primarily for the professional sports industry. Baseball and football fields are designed with underground irrigation systems. Irrigation lines (and in some cases, drainage lines) are installed in pure sand. The grass is then grown in a layer of 75% sand, 20% peat moss, and 5% miscellaneous. While there have been some complaints from the athletes that the underground irrigation system results in a "hard" surface, the irrigation phase does seem to work.

A summary of the association's publications is being forwarded.

Joel Zoeffel

Lee Dillard
November 1979

NASA Tech House
Langley Air Base
(804) 827-3281

Mr. Zoeffel described the water recirculation system in the NASA Tech House. Water from the bath and laundry are collected in a holding tank and recirculated, after filtering through a swimming pool filter and chlorination, to the toilet. The one comment about the system design is that the holding tank was too small and could not accommodate the fluctuations in water use. As a result, a large amount of potentially recyclable water overflows into the sewer line and there are subsequent shortages of flushing water.

Mr. Zoeffel is forwarding the Technical Support Package with detailed information about the various systems in the Tech House.

INTERVIEW REPORT

TEA: Lisa Heschong
DATE: May 16, 1980

INTERVIEWED:

Lee Fisher
National Association of Home Builders - Research Division
Efficient Construction Issues
(301) 762-4200

Mr. Fisher was asked what he saw as the major innovations that were going to occur in residential building technology over the next twenty years. He replied his crystal ball was cloudy, that he was not aware of any recent research or articles in that area, and that projections were rather risky to make. He believed the fastest and most noticeable changes were going to occur in energy technology, such as the use of photovoltaics and other solar systems.

In the area of construction technology he saw a gradual evolution which would not noticeably change the traditional configuration of the single-family house. Wood would continue to be the primary building material, although more manufactured wood products and plastics would find prevalence. He stated although steel stud framing systems have been less expensive than wood for the last decade, and become popular in commercial applications, it has made no penetration into the housing market, illustrating the hold of tradition over economics.

He strongly believes houses are going to have to get smaller although the trend has not started yet. Indeed, the size of the average house in 1979 was the largest in history, at 1,690 square feet. Attics have already almost disappeared entirely. Basements and garages are likely to lose ground slowly, although they are certain to continue in regions with strong basement traditions, such as the Northeast.

He feels there will be advances in appliances and other residential mechanical systems, and that consumer demand will motivate widespread application. Modern appliances, however, will be in contrast to a rather traditional looking house, as close as possible to our image of the kind of house grandparents might have lived in.

Contacts:
Walter E. Ekblaw, President
Scholz Homes, Inc. (Manufactured Housing)
Toledo, Ohio
(419) 531-1601

INTERVIEW REPORT

TEA: Lisa Heschong
DATE: May 1, 1980

INTERVIEWED:

Dr. Otho Wells
Agriculture Extension
University of New Hampshire
Durham, New Hampshire 03824

Dr. Wells has been developing a sand-culture greenhouse at the University of New Hampshire which he calls a modified hydroponic system. They have been growing vegetables such as tomatoes, cucumbers, and broccoli with great success in the cold New Hampshire climate. I asked him primarily about irrigation issues.

One foot of washed sand is regularly irrigated so that only a "pencil-sized" trickle of water drains out to indicate that water is flowing. When the plants are young (6" height) they are irrigated at .10 gal/sq. ft./day. 40 days later they are irrigated at .48 gal/sq.ft./day. Essentially all of this water is absorbed and used by the plants. As the plants get larger and the weather warmer, the plants' demands for water rises proportionately.

INTERVIEW REPORT

TEA: Lisa Heschong
DATE: May 7, 1980

INTERVIEWED:

Professor Edward B. Allen
Professor of Building Technology
Department of Architecture
Massachusetts Institute of Technology

Professor Allen has been teaching and researching building technology at the Massachusetts Institute of Technology for the last dozen years. He was asked what he thought were the coming innovations and changes in residential construction. He felt the greatest changes were going to occur in response to the increasing cost of energy and of wood.

He believes the residential building industry will continue to be a field of small entrepreneurs, who can get in and out of the business quickly. Houses will continue to build on-site, although more and more pre-fabricated components, as contrasted with pre-fabricated systems, will be used. Pre-fabricated bathroom units have developed and are currently on the market but are selling very poorly, probably because they constrain too many other design issues. Tools and assembly techniques which reduce labor will be adapted.

He does not foresee major changes in plumbing technology on the horizon. "The PVC revolution has already happened." Plastic pipes and fixtures are likely to be standard practice very soon.

Scarcity of wood for lumber is likely to promote the use of "wood products" such as oriented strand board, particle board, and other composite wood materials that can be manufactured from small, low-grade trees. Structural members such as wall studs will also be manufactured, as is already done in Scandinavia.

Treated wood foundations are likely to become common as they eliminate an extra construction crew for concrete work and are very easy to insulate, thus good for energy performance.

Energy conservation will also prompt other changes in framing methods. Walls will get thicker to allow for more insulation and sheating systems will get tighter to reduce infiltration. A great deal of wood will be removed from the outer structural skin to allow for better insulation. Likewise, penetration of the exterior walls by plumbing and electrical systems will be largely eliminated.

Building and energy costs will greatly constrict the amount of space people can afford. Multi-family and attached units will become increasingly common. Houses will be squeezed for space, and so spaces currently unfinished and used for storage, such as basements and attics will be used for fully habitable space. Economizing on space will become a major selling point for all equipment.

Allen believes that home computers will be used to regulate energy use, turning off lights, switching to the most economical heating mode, etc. Perhaps motion or acoustic detectors will be used to activate spot radiant heaters and other "person-sized" systems. Heat exchangers will be used to control the ventilation of these very tight houses and to recover the maximum possible amount of heat.

Allen does not know of any current effort to look at these changes at a systematic level, such as was attempted during Operation Breakthrough sponsored by HUD a decade ago. Rather, innovations are occurring field by field.

INTERVIEW REPORT

TEA: Lisa Heschong
DATE: May 16, 1980

INTERVIEWED;

Walter Ekblaw, President
Scholz Homes, Inc.
3103 Executive Parkway
Toledo, Ohio 43606
(419) 531-1601

Scholz Homes, Inc. is the third largest manufactured housing producer in the country. They pre-fabricate all of the framing and skin components of a house and ship them, unassembled, to the building site. They build about 3000 homes a year and ship in a 40 state area.

Mr. Ekblaw was asked how on-site waste treatment might be affected by manufactured housing in the next twenty years. He felt it had little relation, as any waste treatment system was completely the responsibility of the local site contractor. Scholz homes had originally attempted to include a pre-fabricated wet core into their houses, but ran into two major problems. One problem was the "morass" of local code variations, so that no single wet core would satisfy all applicable codes. The variation forced Scholz to build to the highest, possible standard, which kept them from being cost-effective. The second problem was that a fixed wet core restricted flexibility for the consumer, and so lowered the marketability of the houses. Custom arrangements of bathroom and kitchen equipment is a major selling point in otherwise uniform houses. For these two reasons plumbing systems were dropped from the product. Mr. Scholz feels strongly that a uniform national code would greatly aid manufactured housing and thus help to lower housing costs.

Mr. Scholz believes that manufactured housing is going to gain an increasing share of the residential market. Currently, he says, about 60% of the single-family starts in the country can be attributed to "component producers," which includes all levels of pre-fabrication. This breaks down as:

20 - 22%	home manufacturers (framing and shell systems)
30 - 35%	pre-fabricated components from large lumber yards
3 - 8%	sectional and modular homes

Contacts:

Dick Bullock
National Institute of Building Sciences
Washington, D.C.
(on pre-fabrication issues)

Walt Benning
Manufactured Housing Institute
Washington, D.C.
(on mobile home issues)

Ted Cahouse
Continental Homes of New England
Nashua, New Hampshire

John Bemis
Acorn Housing
Concord, Massachusetts

INTERVIEW REPORT

TEA: Lisa Heschong
DATE: May 16, 1980

INTERVIEWED:

Walter Benning, President
Manufactured Housing Institute
Washington, D.C.
(703) 979-6620

Mr. Benning feels that available waste treatment systems pose a major limitation for mobile home sites. Most mobile home communities tie into existing sewer lines. Smaller and more rural sites use septic systems. He thought that community scale treatment plants could greatly free mobile home developments from site constraints.

Some statistics: 276,000 mobile homes were sold in 1979 as compared to 560,000 conventional homes sold*, or one out of three single family houses sold were mobile homes. The ratio had been about one in four in previous years. Mr. Benning projects that mobile homes will soon become the majority of the market, perhaps three out of five by 2000.

The average cost of a single-wide unit is $8,800 and of a double-wide $19,000. 70% of the sales are in single-wide, 30% in "multi-section." 27% of the market are under 30 years old. 27% are retired or "empty-nesters." The balance is mixed.

The "sunbelt" has the greatest number of mobile homes. California is the single largest state. The Midwest ranks 3rd, Mid-Atlantic 4th, and the Northeast last.

There are 5,000,000 existing mobile homes. About 50% are in parks and 50% on individual lots. The average size of a park is 150 homes, varying from 20 to 600. The average occupancy is 2.3 people/unit, and 7 single-wide units per acre (net) or 4 double-wide units per acre. The density has been going down as mobile home parks acquire a more residential image and community facilities. The institute is currently lobbying for mobile homes to be acceptable in standard residential zoning.

Mobile homes are built to a national code specifically for mobile homes, giving them a distinct advantage over "manufactured" housing, i.e., panelized systems, etc. There are 540 factories in the country. The average shipping distance is 300 miles at a cost of $3.50 to $4/mile, making mobile homes a very regional industry.

Sales: 1980 (projected) - 240,000 units. 1979 - 276,000. 1978 - 274,000.
1977 - 262,000.

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*does not include own-built houses.

Leo Weitzman
EPA Office of Solid Waste

Martha Monserrate
May 30, 1980

Mr. Weitzman states that although PCB's may be used in making carbonless copy materials they are in no way used as components in newspaper or magazine ink. Since PCB' s are oily substances which, in some cases, take years to dry, they would not be practical as newspaper or magazine ink ingredients.

James Renson

Martha Monserrate
May 21, 1980

National Association of Printing
 Ink Manufacturers
(914) 698-1004

According to Mr. Renson, polychlorinated biphenyls (PCB's) have not been used as direct components in newspaper or magazine ink for at least the past 7-8 years. PCB's may, however, still be used in making certain pigments which are, in turn, used to make printing ink. Mr. Renson states that, in any case, the PCB's are diluted to trace levels (less than 50 ppm) in any ink that is actually used for printing.

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APPENDIX C

Five Anaerobic Digester Designs for the Base Case House

The following assumptions are basic to all four digester designs:

- refuse grinder--installed in the utility room to handle yard, food, and paper wastes. The water requirements of the grinder are similar to those of a conventional garbage disposal.

- toilet--grinder or air assist type. The amount of water used per flush varies, but in each design there are 3.5 flushes/c/day.

- grey water--treated separately.

- waste generation--assumed as follows:

Water	Wet Weight (per capita/day)	Reference
feces	226 gm (0.5 lb)	a,c
urine	997 gm (2.2 lb)	a,c
food	333 gm (0.72 lb)	d,e
yard wastes	368 gm (0.81 lb)	d,e

- peak flows--it is clear that in many areas of the country, yard wastes will be contributed to the system only seasonably while in others yard wastes will be more evenly contributed. For the present we will ignore problems of seasonal variation. A safety factor of two will be used to account for daily variations.

- solids retention time--the solids retention time or SRT is a measure of how long the wastes need to be held in the digester both for optimum gas production and sludge stabilization. The SRT varies considerably with temperature up to about 95°F (35°C) and remains relatively constant after that point. Also gas production is most efficient at 95°F. We will assume the use of solar collectors to provide energy needed to maintain 95° ± 5°F. The mimumum SRT recommendation is 10 days; we will assume 20 days. As a backup, additional sludge stabilization will occur in sludge storage. Wastes are assumed to be completely mixed throughout the digestion process.

- the following values are assumed to be the main indicators of the required digester size and gas production potential:

Value	Used to Determine
Total dry weight	% solids concentration
Total volatile solids	Amounts of availabe carbon and nitrogen
Carbon/nitrogen ratio	Volume of gas produced
Total waste and water	Required digester volume

REFERENCES

(a) Siegrist, R.L., Woltanski, T., Waldorf, L., "Water Conservation and Waste Water Disposal". ASAE Publication 5-77.

(b) Microphor, Inc., "Water Conservation Begins Here".

(c) Leckie, J., et al., Other Homes and Garbage, 1975.

(d) Hudson, J.F. and Alford, M.R., "Projections of Solid Waste Management Costs" for Resource Conservation Committee. February 1, 1979.

(e) Franklin Associates. "Analysis of Environmental and Economic Impacts of Waste Reduction Procedures and Policies". September, 1977.

(f) Telephone conversation, Bob Siegrist.

(g) EPA Process Design Manual: Sludge Treatment and Disposal.

(h) Fisk, A.T. et al. "Preliminary Design of a Household Refuse Grinder", EPA, NTIS #PB-256-503, 1973.

(i) Serling, S.A. and Alsten, C. "An Integrated, Controlled Environment Aquaculture Lagoon Process for Secondary or Advanced Wastewater Treatment." Presented before the Conference on Performance and Upgrading of Waste Stabilization Ponds, Utah State University, 1978.

CALCULATIONS FOR DESIGN 1

In Design 1, a limited amount of paper wastes are added to the digester. These wastes include papers used to wrap foods, paper towels and napkins. Newspapers are not considered as an input in this design.

The toilet uses ½ gallon (1.90 liters) per flush. The calculations for Design 1 are summaried in Table 5.

Toilet Wastes

Wastes: Feces + urine = total waste
226 gm + 997 gm = 1223 gm/c ≈ 1.2 ℓ/c/day

Water: 1.89 ℓ/flush x 3.5 flushes/c/day = 6.6 ℓ/c/day
Waste + water = Total Toilet Output
1.2 ℓ + 6.6 ℓ = 7.8 ℓ/c/day

Refuse Grinder

Reference A indicates that approximately .8 to 1.5 gallons of water are generated to transport the 50 gm (dry weight) of food wastes produced per capita per day. These produce a waste water with 1% solids.

$$\frac{50 \text{ gms}}{1.0 \text{ gallon}} \times \frac{1 \text{ gal.}}{3785 \text{ gm.}} \times 100\% = 1\%$$

For optimal operation of an anerobic digestion system a much higher solids content of 7 to 8% is desirable. We will assume therefore that our refuse grinder can produce a wastewater stream which is 8% solids.

From Table 1 we find that the dry weight of the wastes to be processed in the refuse grinder are:

Food	50 gm/c/day
Yard	276 gm/c/day
Paper	56 gm/c/day

If the wastewater produced by the refuse grinder is to have 8% solids the volume of wastewater produced will be:

$$\frac{382 \text{ gm}}{.08} = 4775 \text{ gms} = 4.8\ \ell/\text{c/day}$$

Total Wastewater Flow

Toilet	7.8 ℓ/c/day
Refuse Grinder	4.8 ℓ/c/day
Total Wastewater Flow	12.6 ℓ/c/day
Total Dry Solids (from Table 1)	503 gm/c/day
% Solids	4%

TABLE 5: ESTIMATED WASTE CHARACTERISTICS

For Design 1

	Net Weight	% Moisture	TS Total Solids (Dry Weight)	% Volital	Total Volital Solids	%C	C	%N	N
	gmcd*		gmcd*		gmcd*		gmcd*		gmcd*
URINE	997	94[c]	60	75[c]	44	14[c]	8.5	18[c]	10.8
FECES	226	73[c]	61	92[c]	56	48[c]	30.0	6.0[c]	3.7
FOOD	333	(85)	50[f]	88[f]	44	54[c]	27.0	3[c]	1.5
YARD WASTES	368	25[c]	276	87[c]	240	54[c]	150.0	3[c]	8.3
PAPER	60	6[c]	56	97[c]	54	40.6[c]	22.7	---	----
TOTAL:	1984		503		438		237.7		24.3

* gmcd = grams per capita per day

Digester Size for Base Case House

$$20 \text{ days SRT} \times \frac{12.6 \text{ liter}}{\text{capita/day}} \times 4 \text{ persons} = 1008 \text{ liters (266 gallons)}$$

A 1500 liter (400 gallon) tank would allow 508 liters (134 gal) above the liquid surface for gas collection.

Gas Production

Gas production calculations are based on the figures presented in the EPA process design manual for Sludge Treatment and Disposal. Gas production rates of 16 to 20 ft.^{3} Bio gas per lb. of volital solids destroyed are quoted and a volital solids destruction of from 35 to 45% are suggested. Assuming optimal conditions for our digester we will assume:

Gas production at: $\frac{20 \text{ ft}^3 \text{ Bio gas}}{\text{lb VS destroyed}} = \frac{1.25 \text{ m}^3 \text{ Bio gas}}{\text{kg VS destroyed}}$

VS destruction at 40%

Heat Value: $566 \text{ Btu/ft}^3 \text{ Bio gas} = 20{,}000 \text{ Btu/m}^3$

From Table 1:

Total VS = 438 gm/c/day

for Base Case House 438 gm/c/day x 4 persons - 1752 gm/day

@ 40% destruction 700 gm/day VS destroyed

Gas production:

$$.7 \text{ kg/day VS destroyed} \times \frac{1.25 \text{ m}^3 \text{ Bio gas}}{\text{kg VS destroyed}} = .88 \text{ m}^3 \text{ Bio gas/day}$$

$$.88 \text{ m}^3 \text{ Bio gas/day} \times \frac{20{,}000 \text{ Btu}}{\text{m}^3 \text{ Bio gas}} = \frac{17{,}500 \text{ Btu}}{\text{day}}$$

$$\frac{17{,}500 \text{ Btu}}{\text{day}} \quad \frac{365 \text{ day}}{\text{year}} = 6{,}387{,}500 \frac{\text{Btu}}{\text{year}}$$

Sludge Production

Sludge calculations are based on the assumption that all of the water entering the digester leaves in the sludge and that solids in sludge equal total solids entering minus VS destroyed.

From Table 1:

Total Solids = 503 gm/c/day x 4 persons

VS destroyed = 700 gm/day

Solids in sludge = 1312 gm/day

Total Wastewater Flow into digester 12.6 ℓ/c/day x 4 persons = 50.4 ℓ/day

@ 97% water = 48,890 gm water/day

$$\begin{array}{lrl} \text{Sludge} & & 48{,}890 \text{ gms water} \\ & + & \underline{1{,}312} \text{ gms solids} \\ & & 50{,}202 \text{ gms sludge @ 2.6\% solids} = 70 \text{ ℓ/day} \end{array}$$

Sludge Storage

annual production of sludge

$$50{,}202\ \frac{\text{gm}}{\text{day}} \times \frac{1\ell}{1000\text{gm}} \times \frac{1\text{m}^3}{1000\ell} \times 365 \text{ day} = 18.32\text{m}^3$$

assume factor of safety of 2

annual storage capacity $\simeq$ 37m^3 (9,500 gallons)

Sludge % N

Assume all nitrogen entering digester leaves in sludge.

From Table 1:

24.3 gm/c/d/ x 4 persons = 97.2 gm/day

$$\frac{97.2 \text{ gm Nitrogen}}{48{,}890 \text{ gm sludge}} = 0.2\% \text{ Nitrogen}$$

Application Rate

Assume ½ of the ¼ acre lot is available for sludge spreading: 1/8 acre or 505 m^2. Annual sludge production = 18.32m^3. Applying 17.84 m^3 of sludge to 505 m^2 lawn results in an application of a 0.01 m layer of sludge.

Nitrogen Applied to Lawn

97.2 gm/day x 365 days = 35.5 kg Nitrogen/years
or 3.5 times the estimate 10 kg/year required*

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*Based on 4 lb Nitrogen/1000 sq. ft. lawn recommended in Crockets Victory Garden.

CALCULATIONS FOR DESIGN 2

In Design 2, the amount of water used to flush the toilet is reduced from 1.89 liters/flush to 0.2 liters/flush--nearly a 90% reduction. This reduction helps to increase the solids concentration in the digester, decrease the sizes of the digester and sludge storage tanks.

Toilet Wastes

Water: 0.2 liters/flush x 3.5 flushes/c/day = 0.07 ℓ/c/day

Waste: 1.20 liters (same as Design 1)
Waste and water = Total Toilet Output
1.20 ℓ + 0.7 ℓ = 1.27 ℓ/c/day

Refuse Grinder

Total Refuse Grinder Output = 4.8 ℓ/c/day (same as Design 1)

Total Waste Flow

Toilet	1.27 ℓ/c/day
Refuse Grinder	4.8
Total Waste Flow	6.07 ℓ/c/day
Total Dry Solids (same as Design 1)	503 gm
% Solids =	8.2%

Digester Size for Base Case House

20 days SRT x 6.07 ℓ/c/day x 4 persons = 485 ℓ

A 750 liter tank would allow 265 liters above the liquid surface for gas collection.

Gas Production

Gas production calculations are based on the figures presented in the EPA process design manual for Sludge Treatment and Disposal. Gas production rates of 16 to 20 ft.^{3} Bio gas per lb. of volital solids destroyed are quoted and a volital solids destruction of from 35 to 45% are suggested.

Gas production at: $\frac{20 \text{ ft}^3 \text{ Bio gas}}{\text{lb VS destroyed}} = \frac{1.25 \text{ m}^3 \text{ Bio gas}}{\text{kg VS destroyed}}$

VS destruction at 40%

Heat Value: 566 Btu/ft^3 Bio gas = 20,000 Btu/m^3

From Table 1:

Total VS = 438 gm/c/day

for Base Case House 438 gm/c/day x 4 persons = 1752 gm/day

@ 40% destruction 700 gm/day VS destroyed

Gas production:

$$.7 \text{ kg VS destroyed} \times \frac{1.25 \text{ m}^3 \text{ Bio gas}}{\text{kg VS destroyed}} = .88 \text{ m}^3 \text{ Bio gas/day}$$

$$.88 \text{ m}^3 \text{ Bio gas/day} \times \frac{20{,}000 \text{ Btu}}{\text{m}^3 \text{ Bio gas}} = \frac{17{,}500 \text{ Btu}}{\text{day}}$$

$$\frac{17{,}500 \text{ Btu}}{\text{day}} \quad \frac{365 \text{ day}}{\text{year}} = 6{,}387{,}500 \frac{\text{Btu}}{\text{year}}$$

Sludge Production

Solids in sludge (same as Design 1) 1312 gm/day

Wastewater flow into digester

6.07 ℓ/c/day x 4 persons = 24.3 ℓ/day

@ 95% water .. 23.07 ℓ water/day

Sludge production

23,070 gm water/day
1312 gm solids/day
24,382 gm sludge/day ≃ 25 ℓ/day

Sludge Storage

Annual production of sludge

$$\frac{25\ell}{\text{day}} \times \frac{1\text{m}^3}{\ell} \times 365 \text{ day} = 9.1 \text{ m}^3$$

Assume safety factor of 2

Annual storage capacity 18.25 m^3 (4818 gallons)

Sludge N

Nitrogen component same as Design 1

$$\frac{97.2}{42{,}712} \quad \frac{\text{gm nitrogen/day}}{\text{gm sludge/day}} = 2.27\%$$

Application Rate

$$\frac{9.1\ \text{m}^3\ \text{sludge/year}}{505\ \text{m}^2\ \text{lawn}} - 0.018\ \frac{\text{m}}{\text{year}}\ \text{sludge}$$

Nitrogen Applied

97.2 gm/day x 365 days - 35.5 kg Nitrogen/years or 3.5 times the estimate 10 kg/year required

CALCULATIONS FOR DESIGN 3

Methane is a high quality fuel which is easily stored and therefore its production might be worth some extra effort. Design 3 assumes that a solar greenhouse has been installed for the purpose of producing biomass which will be added to the digester to increase biogas production. From Serfling and Alsten (i) we find that while water hyacinths are extremely productive, they are extremely sensitive to temperature and cannot be easily grown in many areas. Even in a solar greenhouse additional heat would be required. Duckweed is much less sensitive to temperature fluctuations and is easier to harvest.

Sizing Duckweek Production Beds

The greenhouse will be designed to provide duckweek production near the summer range* of 50 lbs. dry solids/acre/day.

Methane production from duckweeds is approximately 0.37 m^3 methane/kg of dry solids. Methane has a heat value of approximately 35310 Btu/m^3 compared to the estimated 20,000 Btu/m^3 of biogas. Using these figures a biogas production rate of $\frac{0.66 \text{ m}^3 \text{ biogas}}{\text{kg dry duckweed}}$ can be calculated.

Desired Biogas Production:

Assume one wishes to provide 100% auxilary space and hot water heating plus the cooking requirements for the Base Case House or approximately 30×10^6 Btu/year.

Btu provided by Design 1 = 6,387,500 Btu/year

To be provided by Duckweed = 23,612,500 Btu/year

$\sim 24 \times 10^6$ Btu/year

Duckweed requirement:

$$24 \times 10^6 \ \frac{\text{Btu}}{\text{year}} \times \frac{\text{m}^3}{20{,}000 \text{ Btu}} \ \frac{\text{kg duckweed}}{.66 \text{ m}^3 \text{ Biogas}} = \frac{1818}{\text{year}} \text{ kg dry duckweed}$$

Duckweed production area required:

$$\frac{1818 \text{ kg duckweed}}{\text{year}} \times \frac{1 \text{ year}}{365 \text{ days}} \times \frac{\text{acre/day}}{50 \text{ lb duckweed}} \times \frac{4047 \text{ m}^2}{\text{acre}} \times \frac{1 \text{ lb}}{.454 \text{ kg}}$$

$$= \sim 888 \text{ m}^2 \text{ duckweed beds}$$

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* Serling, S.A. and Alsten, C. "An Integrated, Controlled Environment Aquaculture Lagoon Process for Secondary or Advanced Wastewater Treatment." Presented before the Conference on Performance and Upgrading of Waste Stabilization Ponds, Utah State University, 1978.

Wastewater Flow

Assume duckweed is processed in the refuse grinder at 8% solids. All other wastes the same as Design 1.

$$\text{Duckweed} \quad \frac{1818 \text{ kg duck}}{\text{year}} \times \frac{1 \text{ year}}{365 \text{ days}} \times \frac{1 \text{ wastewater}}{.08 \text{ solids}} = 62.2 \ \ell/\text{day}$$

Total wastewater flow for 4 persons:

Toilet	31.6 ℓ/day
Other refuse	19.2 ℓ/day
Duckweed	62.2 ℓ/day
	113 ℓ/day

Total dry solids:

Design 1	2012 gm/day
Duckweed	4980 gm/day
	6992 gm/day

% Solids: 6%

Digester Size for Base Case House

113 ℓ/day x 20 day SRT - 2260 ℓ

A 3000 ℓ tank would provide 740 ℓ above the liquid surface for gas collection.

Sludge Production

Estimate that duckweed is similar to green garbage at 78% volital solids and destruction rate of 40%.

Duckweed solids in sludge = (.60 x .78 + .22) 4980 =

sludge solids duckweed = 3426 gm/day solids

Design 1 = 1312 gm/day solids

Total: 4738 gm/day

Water in sludge:

.96 x 113 ℓ/day = 108 ℓ/day

Sludge:

water 108,000 gm/day

solids 4738 gm/day
112,738 gm/day 4% solids

Sludge Storage

annual sludge production

$$112{,}738\ \frac{\text{gm}}{\text{day}} \times \frac{\text{m}^3}{10^6\text{gm}} \times \frac{365}{\text{year}}\ \text{day} = 41.15\ \text{m}^3/\text{year}$$

assume a factor of safety of 2

annual storage capacity ≈ 83m^3

Sludge % N

assume nitrogen content of duckweed solids 3% similar to green garbage

Nitrogen - Design 1, 97.2 gm/day - duckweed (4980 gm/day x .03)
149 gm/day

Total N = 246.6 gm/day or 0.22% N

Application Rate

$$\frac{41.15\text{m}^3\ \text{sludge/year}}{505\text{m}^2\ \text{lawn}} = 0.08\text{m}\ \frac{\text{sludge}}{\text{year}}$$

Nitrogen Applied to Lawn

246.6 gm/day x 365 = 90.009 kg/year

estimated requirements

CALCULATIONS FOR DESIGN 4

This variation provides for an increase in Biogas production through the addition of biomass in the form of paper. In this variation all paper products which are generated within the home including newspaper, paperboard, magazines, etc. are processed in the refuse grinder.

Initially, concern was experessed regarding the possibility that PCB's and metals in newspapers and magazine ink might concentrate in the digester to the point that they cause the digester to malfunction or cause the sludge to become hazardous. However, James Renson of the National Association of Printing Ink Manufacturers assured us that PCB's are no longer used in those inks and the metals concentrations in the volumes we are considering are two low to warrant concern.

Paper Wastes

Total paper waste generation is estimated at 662 gm/c/day(*). Design 1 accounted for the incorporation of 60 gm/c/day of misc. paper. Thus, this design calls for an increased paper addition of approximately 600 gm/c/day.

At 6% moisture content the additional paper would increase the dry solids loading by 564 gm/c/day. Processed in the refuse grinder to

8% solids or 7.05 ℓ/c/day.

Total Wastewater Flow

Toilet (Design 1)	7.8 ℓ	
Refuse Grinder (Design 1)	4.8	
Additional paper	7.05	
	19.65	ℓ/c/day

Total Solids

503 gm/c/day (Design 1)

564 " paper

1067 gm/c/day

or 5.4% solids

Digester Size for Base Case House

20 day SRT x 19.65 ℓ/c/day x 4 persons = 1570 ℓ (415 gallons)

A 2200 ℓ (600 gallon) tank would provide 630 liters (185 gallons) above the liquid surface for gas collection.

Gas Production

Assume paper is 97% volital solids

Total volital solids

From Design 1	438 gm/c/day
Additional paper (564 x .97)	547 "
Total:	985 gm/c/day

40% vs. destruction

.4 x 985 = 394 gm/c/day vs. destroyed

For house with 4 persons 1576 gm/day vs. destroyed

Gas Produced

$$\frac{1.25\text{m}^3\text{ Biogas}}{\text{Kgm vs. destroyed}} \times \frac{1.576\text{ kg. vs. destroyed}}{\text{day}} = \frac{1.97\text{m}^3\text{ Biogas}}{\text{day}}$$

$$\frac{1.97\text{m}^3\text{ Biogas}}{\text{day}} \times \frac{20{,}000\text{Btu}}{\text{m}^3\text{ Biogas}} \times \frac{365\text{ day}}{\text{year}} = 14.38 \times 10^6\text{Btu/year}$$

Sludge Production

Total Solids = 503 + 564 = 1067 g/c/day

Volital solids = 438 + 547 = 985 g/c/day

Solids in sludge

= (1067 - 985) + (.6 x 985) = 673 gm/c/day

Water = 19.65 ℓ/c/day x .94.6 = 18.59 ℓ/c/day

Sludge = 18590 gm/c/day water
673 " solids
19263 gm/c/day sludge

3.5 solids

Sludge Storage

$$19263\text{ gm/c/day} \times \frac{\text{m}^3}{\text{gm}} \times 4\text{ persons} \times 365\text{ day} = 28.12\text{m}^3$$

(7424 gallons)

factor of 2 for safety

annual storage capacity 57m^3

Sludge %N

Paper has almost no nitrogen so nitrogen from Design will be used.

$$\frac{97.2\text{ gm nitrogen/day}}{77{,}052\text{ gm}} = 0.13\%\text{N}$$

Application Rate

$$\frac{28.12\text{m}^3 \text{ sludge/year}}{505\text{m}^2 \text{ lawn}} = .055\text{m sludge/year}$$

Nitrogen Applied

Same as Design 1.

CALCULATIONS FOR DESIGN 5

The objectives of this design is to process only toilet and food wastes with the objective of producing a stabilized sludge for nutrient recycling. Biogas production would be marginal at best and gas would be most likely vented rather than used.

Wastes

Toilet (Same as Design 1) 7.8 ℓ/c/day
121 gm/c/day solids

Food (from Table 1 assume garbage disposal producing 8% slurry)

Total solids food = 50 gmcd

@ 8% solids = 625 g m/c/day = .62 ℓ/c/day

Total Wastewater flow

Toilet	7.8	ℓ/c/d
Food	.62	"
	8.42	ℓ/c/d

Solids = 171 gmcd

2% solids

Digester Size for Base Case House

20 days SRT x 8.42 ℓ/c/day x 4 persons = 673ℓ

(177 gallons)

A 1000 liter (250 gallon) would provide 327 liters (73 gallons) above liquid surface for gas collection.

Gas Production

From Table 1 the V.S. for Toilet & Food wastes are

Urine	44 gmcd
Feces	56
Food	44
	144 gmcd

Base Case house @ 4 persons

576 gm VS/day

@ 40% destruction 230 gm VS destroyed/day

Gas Production

$$\frac{1.25\ \text{m}^3\ \text{Biogas}}{\text{kg VS destroyed}} \times \frac{0.23\ \text{kg VS destroyed}}{\text{day}} = .29\ \text{m}^3\ \frac{\text{Biogas}}{\text{day}}$$

Heat value

$$.29\ \text{m}^3\ \frac{\text{Biogas}}{\text{day}} \times \frac{365\ \text{day}}{\text{year}} \times \frac{20{,}000\ \text{BTU}}{\text{m}^3\ \text{Biogas}} = 2{,}098{,}750\ \text{BTU/year}$$

Sludge Production

Total Solids = 171 gmcd

Volital Solids = 144 gmcd

Solids in Sludge = (171-144) + (.6 x 144) = 113 gmcd

Water in Sludge = 8.42 ℓ/c/day x 98% water = 8.25 ℓ/c/day

Total Sludge =	water	8250 gm/c/day
+	solids	113
	sludge	8363 gm/c/day @

Sludge Storage

Annual sludge production = 3.05 m^3/year

Assume factor of 2

annual storage capacity 6.1 m^3

(1611 gallons)

Sludge Nitrogen Content

From Table 1 Nitrogen Content influent

Urine	10.8 gmcd
Feces	3.7
Food	1.5
	16.0 gmcd

Base Case House @ 4 persons

$$16.0 \text{ gmcd} \times 4 = 64 \text{ gm/day}$$

$$\frac{64 \text{ gm N/day}}{33452 \text{ gm sludge/day}} = 0.2\% \text{ Nitrogen}$$

Application Rate

$$\frac{3.05 \text{ m}^3\text{/year sludge}}{505 \text{ m}^3 \text{ lawn}} = .006 \text{ m } (.24 \text{ in}) \text{ sludge/year}$$

Nitrogen loading to lawn

$$64 \text{ gm/day} \times 365 \frac{\text{days}}{\text{year}} = 23.36 \text{ kg/year}$$